MARCH, 1959

Welding Journal

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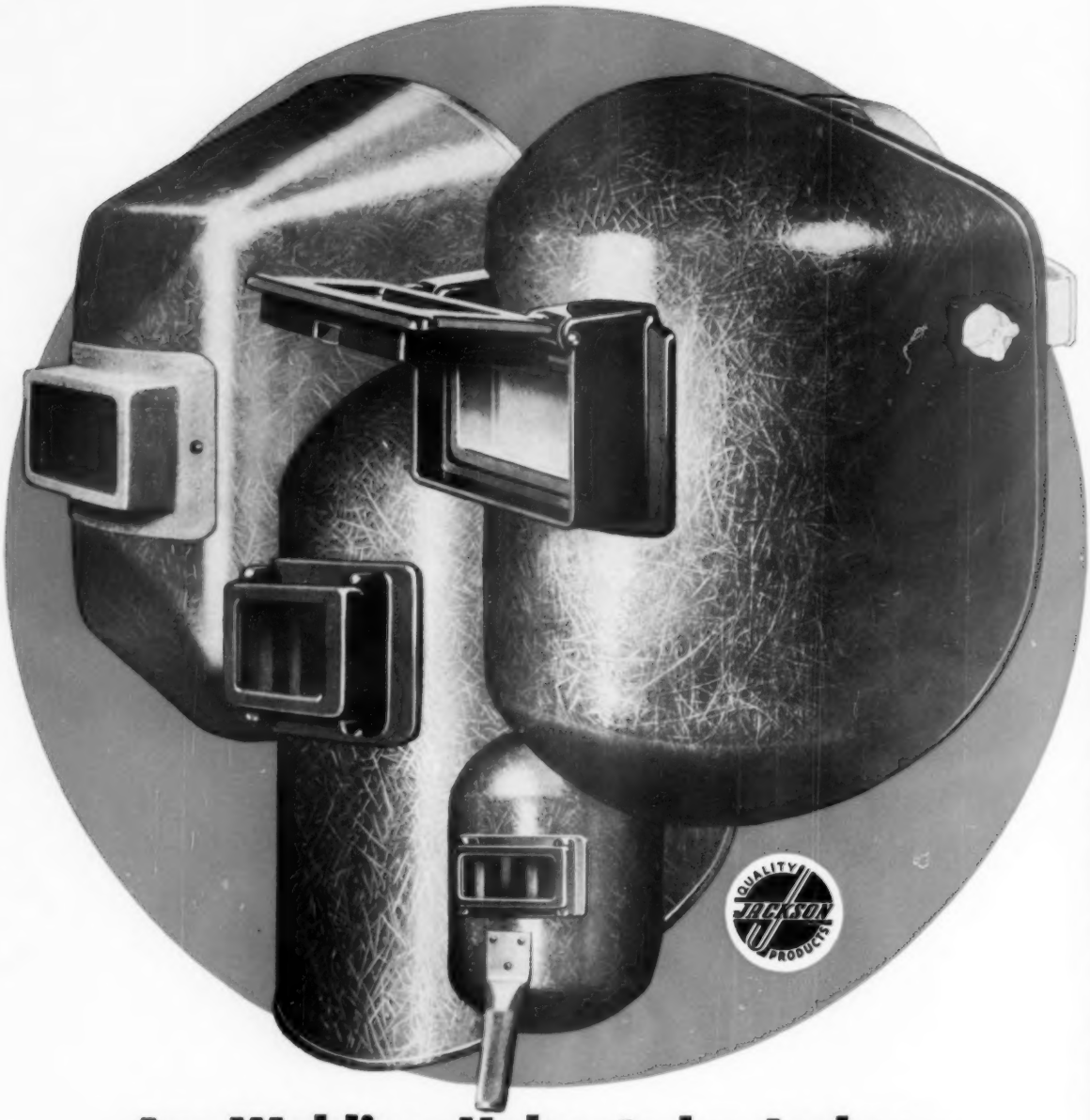

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PRESS-TIME NEWS... about ...People ...Welding ...Products

Canadian Building Incident Provides Full-Scale Test of Welded Construction

On September 6th the 11-story welded steel framework of a new building being erected in Toronto, Canada, collapsed in a high wind and was completely demolished. Two consulting firms have now reported their findings as to the cause of the collapse.

Findings of the two firms state that because of insufficient temporary bracing during erection, the steel framework, which had been welded up to the seventh floor, was unable to withstand the extremely high local winds.

The January 3rd edition of the Toronto newspaper, The Financial Post, made the following statement: "The collapse proved an invaluable test of full-scale welded construction. Welding of the steel framework on the 11-story building had been completed up to and including the seventh floor level. When the building collapsed, welded sections were subjected to tremendous stresses—far greater than any they would be forced to bear under normal conditions. Experts were amazed at the way the welds took the strain. Inspection by the Canadian Welding Bureau showed that only one of several hundred had failed."

The consultants, architects and other structural engineer authorities gave unqualified approval to both the unusual design of the building, which was free of interior columns, and the welded connections.

CHICAGO'S FRONT DOOR—GRANT PARK

Visitors to the AWS 40th Annual Meeting and the 7th Welding Show in Chicago during the week of April 6th will have an opportunity to view this impressive sight of the city's skyline. In the foreground is Grant Park, built entirely of land reclaimed from Lake Michigan

IAA to Meet in New Orleans

A technical session on safety with major emphasis on safe practices in the use of oxyacetylene processes and equipment will be the feature of one of the sessions of the annual convention of the International Acetylene Association to be held on March 9th and 10th at the Hotel Roosevelt in New Orleans.

The session, to be moderated by H. R. Morrison, Linde Co., New York City, will begin at 9:00 A.M., Tuesday, March 10th, and will include a panel discussion by safety experts from various member companies as well as by representatives from the educational field and from the National Fire Protection Association.

The International Acetylene Association, which is one of the oldest technical associations in the country, was founded in 1898. The 1959 meeting at New Orleans will be the 61st Anniversary Convention of the group.

In addition to the session on plant safety, the 1959 meeting will also include a technical session on acetylene-based chemicals. Under the co-chairmanship of Dr. R. V. Bailey of the Chemical Engineering Department, Tulane University, New Orleans, and B. G. Caldwell, Dow Chemical Co., Plaquemine, La., the session will include a presentation on the Fortier plant of the American Cyanamid Co. at New Orleans, as well as a report and open forum discussion on proposals by the IAA Transmission Committee for an industry-wide guide covering acetylene transmission systems. W. Y. Scofield, Air Reduction Co., Inc., New York City, is chairman of the latter committee.

At the Morehead Medal Dinner, to be held in the Grand Ballroom of the Roosevelt Hotel on the same evening, presentation will be made to this year's recipient of the association's annual award to the individual who, in the judgement of the IAA officers and directors, has done the most to advance the industry or the art of producing or utilizing calcium carbide or acetylene. H. S. Sutherland, president, Shawinigan Chemicals Ltd., Montreal, Canada, and president of the IAA, will preside.

The 1959 convention of the International Acetylene Association at New Orleans will be the first meeting of the group to be held in that city.

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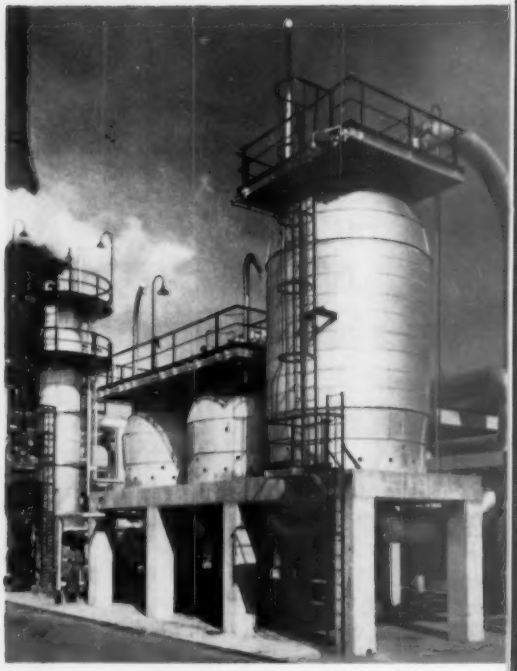
WELDING ZONES

These offshore oil structures were fabricated by the gas-shielded metal-arc process at the plant of the McDermott Fabricators in Morgan City, La. Completed 6061-T6 aluminum weldments were then transported by barge from the Louisiana site to Lake Maracaibo, Venezuela (Courtesy of the Linde Co.)



These three welded reactors are part of new Houdriformer high-severity reforming process unit which upgrades nearly 1,000,000 gal of naphtha daily at Tidewater Oil Co.'s refinery at Avon, Calif. Large reactor in foreground has 5.04-in. thick walls with $2^{5}/_{8}$-in. thick hemispherical heads. The reactors were fabricated of A-301-B firebox steel at Chicago Bridge & Iron Co.'s Birmingham plant

The **Columbia,** winner of th America's Cup, sailed with thi 90-ft aluminum mast. Using the inert-gas process, three 30-ft sections were butt welded together. Fabricated by the Fuller Brush Co. Machine Division, the mast was strong enough to handle the more than 1900 sq ft of sail used (Courtesy of Aluminum Company of America)

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WORLD-WIDE WELDING NEWS

By Gerard E. Claussen

EAST GERMANY

Welded Plate-Girder Highway Bridge Erected in Stockholm

A plate-girder highway bridge, 620 ft long and 72 ft wide, built in Stockholm, is entirely welded with the exception of some riveting on the wind connections and main girder joints. Reported in the August 1958 issue of *Schweisstechnik*, the structure has 75- x 0.71- x 1.02-in. webs of the main flanges and 24- x 1.66-in. flanges. Low-alloy steel ST 52 was used for important parts, meeting Charpy-V specifications of 24 ft-lb at −4° F. The steel was ultrasonically tested. Tack welds and root beads were made with low-hydrogen electrodes which had been stored in an oven at 480° F. Filler beads were made with E6013 electrodes. Inspection required a total of 1230 shop radiographs, while an additional 900 radiographs were made in the field. All steel for the bridge was produced at Czech and East German mills, while fabrication and erection were performed by the East German firm of Lauchhammer.

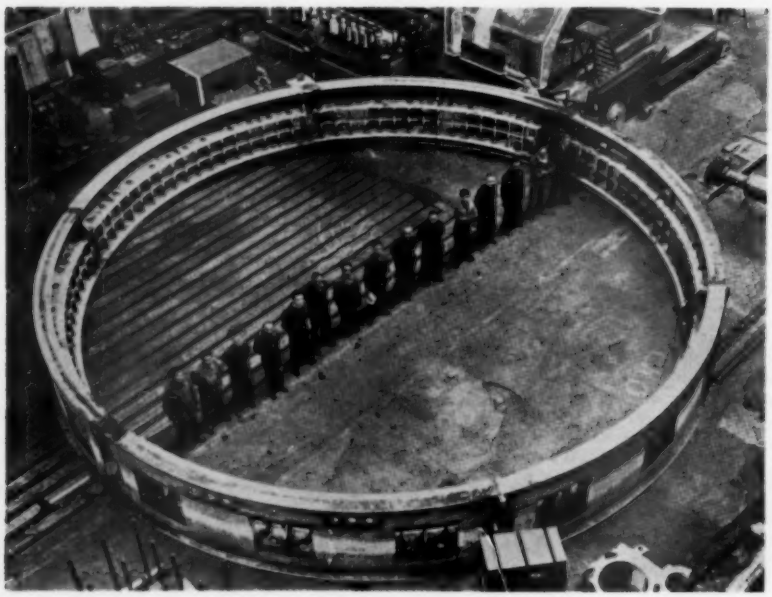
Method of Selection of Steel Devised for Welded Structures

A Leipzig engineer has proposed a "five-point criterion" for the selection of steel for welded structures in the August 1958 issue of *Schweisstechnik*. The criteria are questions to be answered in the affirmative or negative.

1. Tendency to brittle fracture. Does the design create high longitudinal tensile residual stresses which, when added to load stresses or combined with biaxial stresses, tend to cause brittle fractures? Welds over 10 ft long are presumed to have high-tensile residual stresses. Points of intersection of several welds are presumed to have high multiaxial residual stresses.
2. Notches. Do the type and location of a weld favor propagation of destructive fractures? Butt joints are generally less sensitive than fillets, although the air gap in fillet welds may serve as a crack stopper.
3. Is the steel 1 in. thick or over?
4. Is the service temperature of the structure below −13° F?
5. Is the structure subject to impact?

If all five answers are affirmative, a normalized, aluminum-silicon killed open-hearth steel must be used. If three or four answers are positive, a killed open-hearth steel must be used. If only one or two answers are positive, an unkilled open-hearth or blown steel should be used. Five negative answers should determine the use of a blown steel with guaranteed weldability.

ITALY



Frame of a vertical alternator (Courtesy of IIW)

Categories Established for Research Activities

During the summer of 1957 the East German government divided scientific and technical research activities into three categories. Subjects identified by the symbol "Z" were the most important since they are controlled directly by the government's research council. "Z-O" subjects concern a single industry and are introduced by a ministry or other central agency. The final category, "B" subjects, comprises plant-operating problems financed by the plant itself. Research may either be carried out on a cooperative basis between several laboratories or on a contract basis between a plant and an industrial research institute or college.

Welding research in East Germany is concentrated in certain

Dr. GERARD E. CLAUSSEN is associated with Arcrods Corporation, Sparrows Point, Md.

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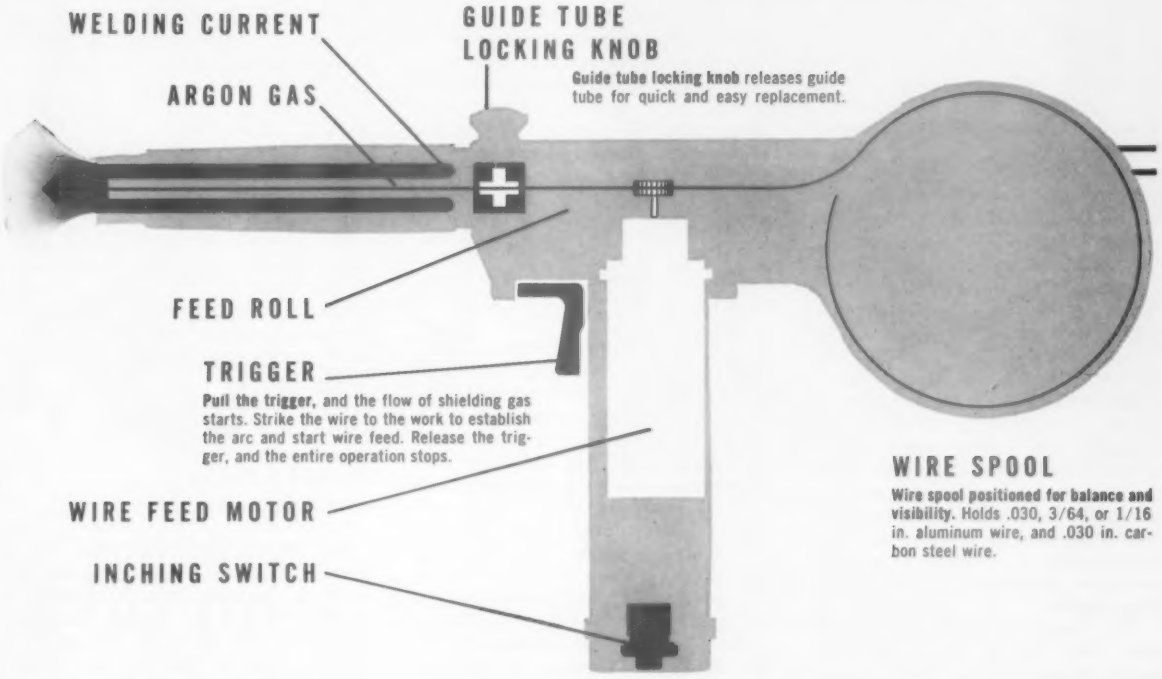
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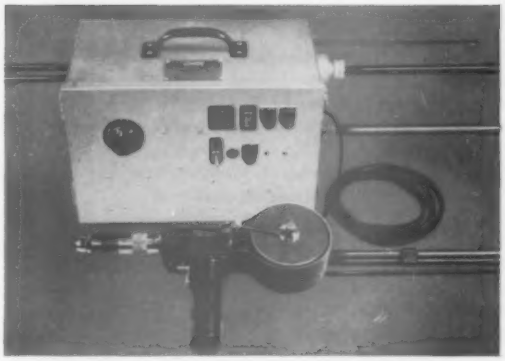

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locations. Among the institutes, the Central Institute for Welding in Halle and the welding laboratories of the German Railways in Wittenberg are the most significant. Plant laboratories sponsoring welding research include the Kjellberg Electrode Plant in Finsterwalde, the Veb Electrode Factory in Berlin and the Veblew Resistance Welding Plant in Hennigsdorf. Welding research is also being conducted in the following colleges: the Heavy Machinery College in Magdeburg, the Freiberg Mining Academy, Rostock University and Dresden Technical College.

Among the contract research subjects of the Central Welding Institute are the automatic surfacing of steel mill rolls, the problems of CO_2 welding in shipbuilding, the fatigue strength of welded aluminum alloys for shipbuilding and stress analysis of mine structures. Assistance was rendered in the following instances: the application of submerged-arc welding to low-alloy steels at the Hohenthurm boiler plant, and the introduction of electro-slag welding at the same plant; the design of small spot-welding machines for the Dresden-Hellerau resistance-welding plant; and the comparison of several automatic surfacing processes for two Magdeburg plants.

The Central Institute cooperated with the Berlin Road Development Bureau to establish design stresses in fatigue for welded highway bridges. The institute also cooperated with Cottbus Technical College and the Niedersedlitz bridge plant to study the static and fatigue strengths of combined joints involving both welding and high-tensile bolts. With Greifswald University the Central Institute measured welding arc temperatures preliminary to automatic welding developments. Other cooperative projects with technical colleges involved stress distribution in fillet welds and the fatigue strength of welded tubular structures.

Calorimetric Studies of Electrodes

A calorimetric study of E6012, E6020 and low-hydrogen electrodes was made by the Finsterwalde laboratory of the East German Welding Institute, as reported in the August 1958 issue of *Schweisstechnik*. The E6020 electrodes were exothermic, producing 4 to 11% more heat than that calculated from current, voltage and time of welding. The other electrodes were less exothermic than the E6020 type. Heat in slag and spatter varied from 8 to 15% of the total heat.

Welding Conference Held in Magdeburg

In April a four-day welding conference was held in Magdeburg with 317 individuals in attendance. During the plant visitations, which were held in conjunction with the conference, demonstrations were given of such processes as hot welding of cast iron, arc-air gouging and CO_2 welding of defects in steel castings, electro-slag welding of $2^3/_8$-in. thick plates and submerged-arc welding of tanks.

AUSTRIA

Historical Highlights of Austrian Welding

The December 1958 issue of *Soudage et Techniques Connexes* contains a brief history of Austrian welding by F. Rapatz, vice president of IIW. Cored electrodes, containing a core of lime or other arc stabilizers and deoxidizers, such as alumina, were sold as early as 1927. The core was 4% by volume of the ingot or bloom from which the wire was produced. The cored electrode was used widely in Central Europe, for example, by the German Navy. Other Austrian developments were the Hafergut "firecracker" process, and the addition of columbium to prevent intergranular corrosion in austenitic stainless steel. Lime-fluorspar type electrode coverings were developed in 1932 to prevent cracks, but porosity was not overcome until 1945.

NETHERLANDS

Fatigue Tests Conducted by Research Group

The December 1958 issue of *Lastechniek* contains an article on pulsating tension fatigue tests made by the Netherlands Fatigue Research Committee on butt welds prepared with E6013, E6015 and E6020 electrodes. The specimens were cut transversely from welds in $^1/_2$-in. mild-steel plate containing 0.13% C, 0.69% Mn, 0.03% Si, 0.020% P, 0.019% S, 0.14% Cu and 0.003% N_2. Welds with the E6013 and E6015 electrodes were made in the "vertical up" position, while the E6020 welds were made in the flat position. Unmachined welds had a fatigue limit at 2 million cycles, 30 to 40% below the plate, of 40,000 psi. The fatigue limit of machined welds was 32 to 36,000 psi. It was also determined that the fatigue limit of machined welds made in plate containing segregations was only 27,000 psi with E6013 electrodes, while approximately the same limit was reached in unsegregated plate with the other electrodes. A "hydrogen-free" heat treatment, 4 hr at 580° F, did not improve the fatigue limit of welds made with the low-hydrogen electrodes.

SOVIET UNION

Tungsten-Arc Welding in Hydrogen Atmospheres

The October 1958 issue of *Svarachnoe Proizvodstvo* describes precision equipment for arc welding tungsten, molybdenum, "Kovar" and nickel sheet. A 0.024-to 0.039-in. diam tungsten electrode was used in a hydrogen atmosphere. A 300-v generator supplied 1 to 10 amp at 40 to 60 v for welding.

Revision Proposed for Electrode Standards

Members of the Leningrad Polytechnic Institute have proposed a revision to the Soviet standard GOST 2523-51 for the arc welding of steel with covered electrodes. As disclosed in the October 1958 issue of *Svarachnoe Proizvodstvo*, four groups of electrode were specified. (1) Two electrodes with 60,000-psi tensile strength were suggested for mild and low-alloy general-purpose steels. One electrode would satisfy low- and the other high-ductility requirements. (2) The classification of low-alloy special-purpose steels would be covered by two more electrodes. They are aimed principally for creep-resistant steels (17,000 psi min for a creep rate of 10^{-5}% per hr at 840° F). An electrode for 3% nickel steel must develop an impact value of at least 15 ft-lb at −256° F. (3) Electrodes were also suggested for welding corrosion-resistant steels, including such types as 321, 347 and 310. (4) The final group would specify electrodes for welding such heat-resistant steels as Types 316 and 330.

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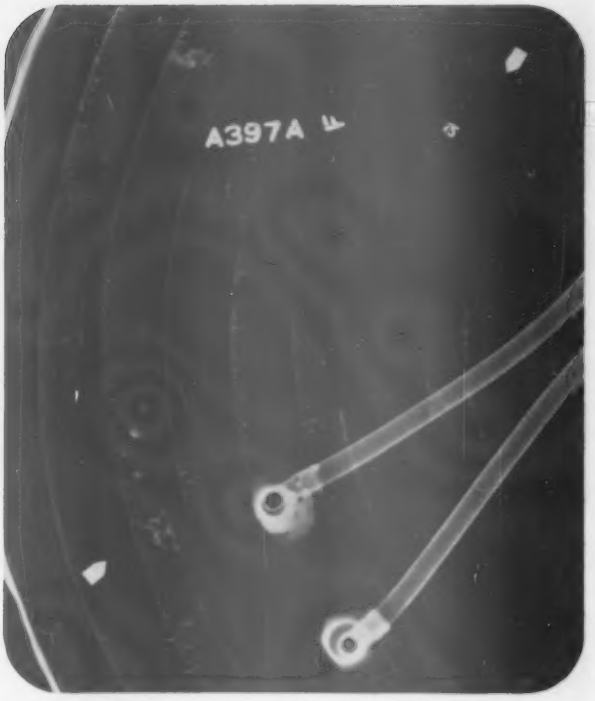
A Cherry-Burrell milk-cooling tank with heat exchanger welded to the bottom.



Radiograph showing welding had flashed, leaving splattered metal spurs.

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For example, the tube heat-exchanger welded on the bottom was radiographed to check for soundness. Early radiographs showed several places where the welding had splattered and formed spurs inside the tubing. This could have caused difficulties. So, the welding technique was altered and later radiographs proved the trouble removed.

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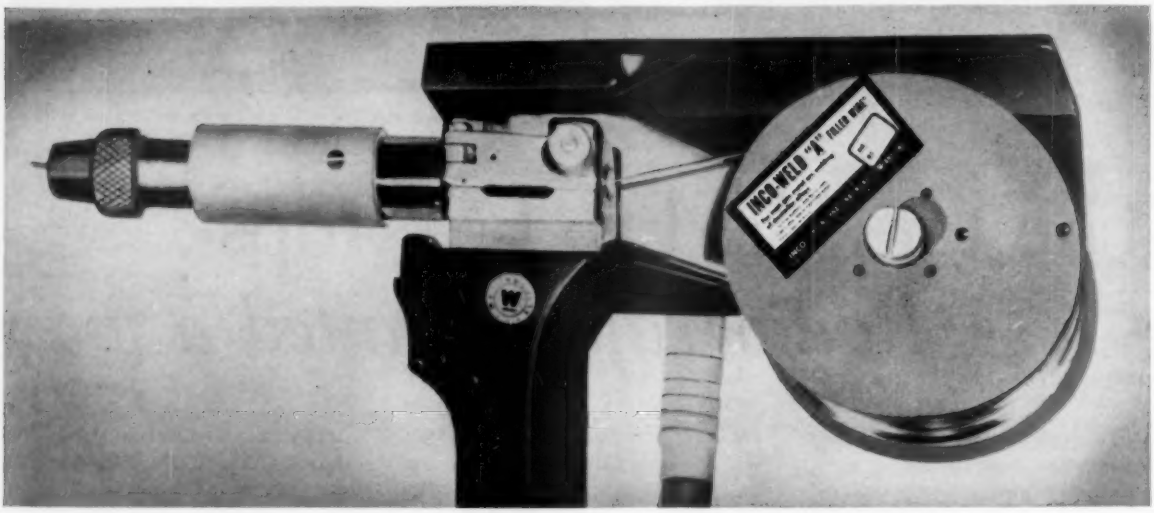

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M. Q., by the way, stands for management quotient. As intelligence quotient is a comparison of mental and chronological age of an individual, so management quotient is a comparison of ability to manage and extent of responsibilities of an individual. To raise the level of M. Q. it is necessary to know its present level and, while self analysis of a business is as difficult as self analysis of personal character, there are ways of getting it done.

There are seven business functions which must be well managed to achieve any degree of success. They include the market, sales, distribution, service, the shop, paperwork and personnel. If management will list these individually and make an honest appraisal of its knowledge of what constitutes good management in each function, a basis of measurement will have been established. Done regularly, say every three months, this will provide a record useful to progress.

Never has so much help been offered in the field of business management as at the present time. Associations, colleges and universities, the Department of Commerce, the business and trade press and manufacturers themselves provide comprehensive and useful help in every phase of business practice. It is almost impossible to avoid being exposed to education in the field of business methods.

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Gene Wedereit

DIRECTOR OF ADVERTISING
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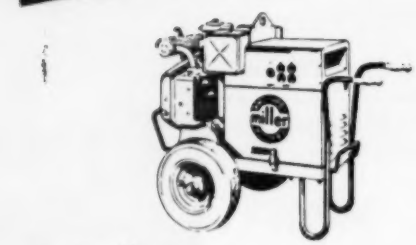

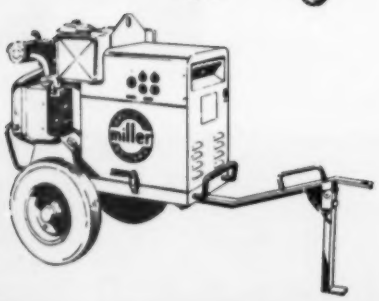

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Welder making a weld, with an over-all view of the pipe line behind him

Welder-Qualification Requirements for Pipe-Line Welders

Qualification tests are designed to determine a welder's ability by means of a limited number of tests and, at the same time, qualify him for a range of pipe diameters, wall thicknesses, materials and welding positions

BY ROBERT R. WRIGHT AND ROBERT S. RYAN

SYNOPSIS. The methods and procedures used in the construction of a pipe line introduce problems that complicate welder qualification. These problems are discussed in this paper as well as the welder-qualification tests which one company has adopted to overcome these problems.

Welder-qualification tests are not a luxury but a necessity which must be substantiated on the basis of satisfactory service performance and safety. The primary purpose of this paper is to describe the qualification tests of one company as a background for suggesting that perhaps there may be a much simpler and more satisfactory method of determining the ability of welders.

A weld in a pipe line must withstand a number of stresses including internal pressure and secondary stresses such as those introduced during construction, weight of soil, temperature changes, and other effects. For this reason, it is necessary to determine the ability of welders by the introduction of some qualification test. Considerable thought must be given the selection of the tests in order to determine the welder's ability on various diameters, wall thicknesses, materials and welding positions. The tests described in this paper are designed to determine the welder's ability by means of a limited number of tests and, at the same time, qualify him for a range of diameters, wall thicknesses, etc.

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Paper to be presented at the AWS 40th Annual Meeting in Chicago, Ill., April 6–10, 1959.

Fig. 1—Completing the bottom portion of a pipe-line weld

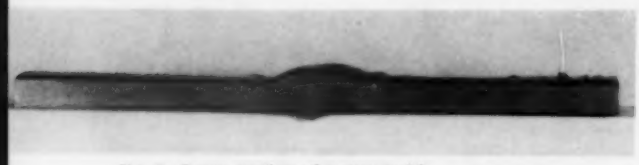


Fig. 2—Cross section of a pipe weld

Most companies in the gas industry have the major portion of their construction done by contractors. This means that, in addition to their own company welders, many contractor welders are welding on their pipe lines. It is not difficult to keep close control on company welders. It is difficult, however, to keep the same control on contractor welders, especially when they move from one job to another. For example, a company can assure that their welders are qualified for all the welding that they might encounter. Since this is not true with contractor welders, the qualification tests must be designed accordingly.

In any industry, welder-qualification tests are only representative of the welds which a welder might encounter because it is not economically feasible to test a welder for each individual weld. Also, the results obtained from these tests are only representative of the welder's ability. A successful qualification does not assure good quality work on the construction job. The ability of a contractor's welder is determined by the Operating Companies of the Columbia Gas System through the use of the qualification tests described in this paper. The work of the welder is inspected during construction to assure that he is performing satisfactorily. The inspection consists of visual inspection as well as nondestructive tests, such as radiography. The rigidity of these qualification requirements is evidenced by the fact that approximately 20% of the welders who have taken these tests over the past two years have failed to qualify.

Pipe-line Welding

In general, pipe larger than 4 in. OD is welded by the manual shielded-arc process. Pipe-line welding is similar to the majority of butt-welding applications where complete penetration is required. However, the welding must be accomplished from one side only in a pipe line. A welder is required to weld in three different positions, i.e., flat, vertical and overhead in making a circumferential weld. The joint design consists of a single-vee-groove weld with a 30-deg bevel and a $^1/_{16}$-in. root opening and nose. There have been a number of discussions concerning the 30-deg bevel and the $37^1/_2$-deg bevel. The 30-deg bevel is the most common in the pipe-line industry because it consistently produces a satisfactory weld joint and requires less weld metal.

It is not possible to position the pipe and make it convenient for the welder to weld in all positions. The bottom of the pipe is normally about 18 in. off the ground which requires the welder to kneel and sometimes lay on the ground while completing the bottom of the weld, as shown in Fig. 1.

The downhill welding technique is used in the majority of pipe-line welding. The reason for this is that downhill welding utilizes higher welding currents which result in faster welding speeds in the wall thicknesses common to the pipe-line industry. It is surprising how proficient a good pipe-line welder is in obtaining a weld bead on the inside of the pipe while welding from the outside. The amount of root-bead penetration can be seen in the cross section of a completed weld, as shown in Fig. 2.

Present Standards

A joint committee of representatives from the American Petroleum Institute and the American Gas Association has published an API Standard 1104, entitled "Standard for Field Welding of Pipelines." This standard has received wide acceptance as the code or acceptable practice for the welding of pipe

lines. Procedures for the radiographic inspection of pipe-line welds and the acceptable limits on the size of defects are also contained in this standard. Many companies have adopted this specification as written while other companies have used it as a guide in setting up their own specifications.

Qualification of Welders

The pipe which a pipe-line welder encounters varies in diameter, wall thickness, welding position and chemical composition. These variables complicate the qualification of the welders. It is not practical to qualify a welder for each variable; therefore, limits have been established which enable one test to satisfy a range for each variable. A welder is required to make at least one test weld for each type of weld for which he is to be qualified. The welding

Fig. 3—Qualification of a welder

procedure used in these test welds must be qualified by a prior test.

Material

The pipe-line materials are generally mild steel. The main constituents include carbon, manganese, phosphorus, silicon and sulfur. The carbon and manganese contents are varied to obtain pipe of various strengths. Pipe becomes more difficult to weld as its strength increases. Therefore, a welder is considered capable of welding any material of an equal or lower strength than that for which he has qualified. For example, if the welder has qualified on material whose yield strength is 46,000 psi, he is also considered qualified to weld on all pipe of the same and lower strength; but he is not qualified to weld on pipe of a higher strength.

Diameter

As the diameter of pipe increases, the welding becomes more difficult because larger diameters contain a greater length of overhead and vertical welding. For this reason, diameter limits have been established. A welder who has qualified on a pipe $10^{3}/_{4}$ in. OD or less is considered qualified to weld all pipe diameters $10^{3}/_{4}$ in. and under; a welder who has qualified on a pipe $12^{3}/_{4}$ in. OD or larger is considered qualified to weld all pipe diameters. For example, if a welder has qualified on a pipe $6^{5}/_{8}$ in. OD, he is qualified to weld all pipe diameters $10^{3}/_{4}$ in. OD, and under.

Wall Thickness

The welding technique for wall thicknesses 0.625 in. and greater is different from that used on wall thicknesses less than 0.625 in. It does, however, incorporate the technique used on the thinner walls. For example, when welding a wall thickness of $^{3}/_{4}$ in., the thickness up to 0.625 in. is welded by the downhill method as is a thinner wall pipe, and the remaining wall thickness is welded by the uphill method. For this reason, a welder who has qualified on a pipe with a wall thickness less than 0.625 in. is considered qualified to weld all wall thicknesses less than 0.625 in. Also, a welder who has qualified on a pipe with a wall thickness of 0.625 in. or greater is considered qualified to weld all wall thicknesses.

Position

When laying a pipe line through mountainous terrain, a welder will be required to make welds in pipe whose axis is inclined at various angles. The qualification test requires that a welder testing to weld on pipe lines must make a butt weld between two fixed pieces of pipe whose axis is inclined at 45 deg with the horizontal, as shown in Fig. 3. Successful completion of this weld qualifies the welder to make butt welds in pipe whose axis is inclined at any angle.

The majority of the welds that are made in the construction of a compressor station are either in the horizontal or the vertical positions, as shown in Fig. 4. Welders qualifying for this work must therefore pass two butt-welding tests. In the first test, the axis of the pipe is in the horizontal position with the pipe remaining in this fixed position during welding. The downhill welding technique is used for the stringer and filler passes while the cover pass is deposited by the uphill method. In the second test the axis of the pipe is held in a vertical position during welding.

Tests for Multiple Qualification

A single test may qualify a welder for all of the welding which he will be required to do if the proper diameter, wall thickness, material and position is selected. For example, a welder who has qualified on 52,000 psi yield strength pipe, $12^{3}/_{4}$ in. OD, 0.625

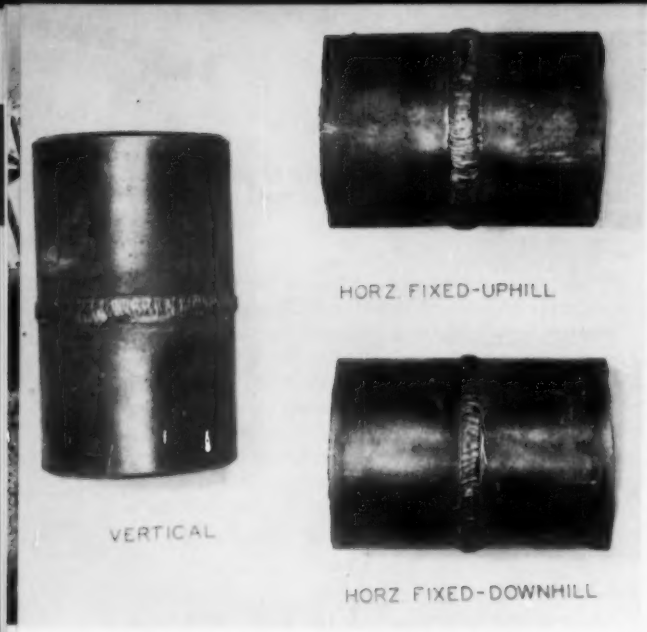


Fig. 4—Pipe welds made in the vertical, horizontal-fixed uphill and horizontal-fixed downhill positions

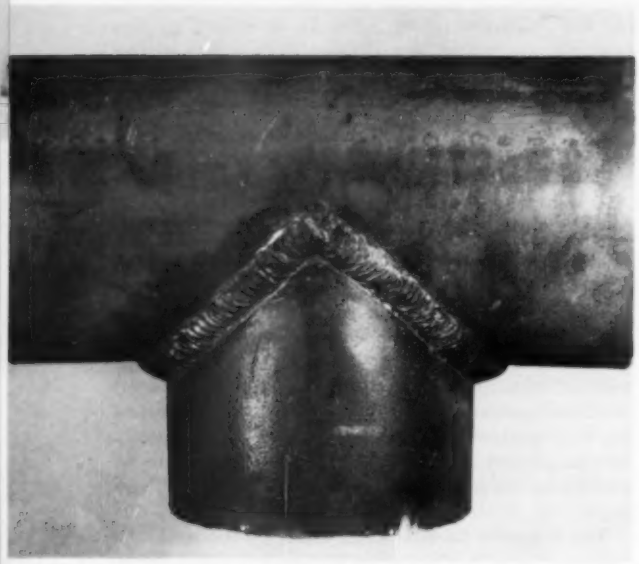


Fig. 5—Completed branch-connection test weld

in. wall thickness and in the 45-deg position would be considered qualified to weld pipe of all yield strengths less than 52,000 psi, regardless of diameter, wall thickness or position. The qualification thickness should be less than 0.625 in. if it were doubtful that the welder would encounter pipe 0.625 in. or greater.

There is a considerable amount of welding during the construction of a pipe line that requires welders with additional requirements other than those described for butt welding. These welders must field fabricate such things as branch connections. Also, they must cut, fit and weld the section of pipe that has been left out at road crossings. These welders must be good fitters as well as good welders. The qualification tests which they are given are designed to test both of these skills. The qualification test consists of cutting, fitting and welding a branch connection held in a fixed position with the outlet down, as shown in Fig. 5. The branch connection is size on size in the material, wall thickness and diameter range in which the welder will be required to weld.

Many times a welder is required to weld on a pipe containing gas. This welding, called hot-tap welding, is usually completed by company welders; however, occasionally contractor welders must be used. A special qualification test using a pressure cylinder has been designed to determine the welder's ability for this type of work. The pressure cylinder is a piece of 6- to 12-in. diam pipe capped at each end and subjected to an internal air pressure of 100 psig. Low-hydrogen electrodes are used for making hot-tap weld; therefore, they must be used in the test since the welding technique is different from that required with the E6010 electrode. The welder makes two

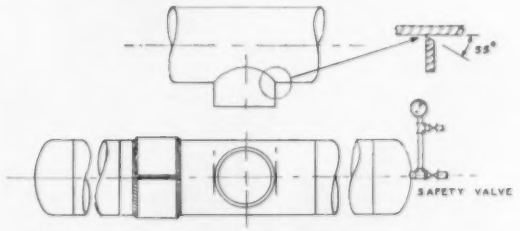


Fig. 6—Hot-tap pressure cylinder

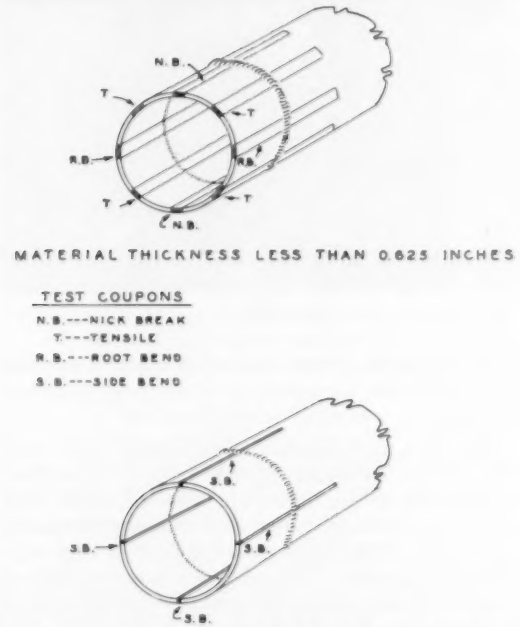


Fig. 7—Location of test coupons

welds on this cylinder, as shown in Fig. 6. The first weld consists of a band which is split, fitted around the cylinder, butt welded together with the welds in the 3 o'clock and 9 o'clock positions and fillet welded to the cylinder. This weld simulates a number of repair welds that are made from time to time in the maintenance of a pipe line. The second weld is a branch connection welded to the side of the pressure cylinder. The size of the branch connection can be either the same size as or one size smaller than the pressure cylinder.

Testing of the Completed Welds

Butt Welds

The test welds are tested by a destructive examination when the welds are completed. Eight evenly spaced coupons are cut at right angles to the weld with each containing a portion of the weld in the case of pipe less than 0.625-in. wall thickness. The coupons are cut from the test weld at locations shown in Fig. 7. These test coupons are cut from the pipe with a special coupon cutter, as shown in Fig. 8.

The four tensile coupons are pulled to destruction under a tensile load. The coupons are acceptable if they rupture in the base metal or if they fail in the weld and the calculated unit tensile strength is greater than the minimum specified tensile strength of the electrode used in the filler passes. If the fracture occurs in the weld, the fractured surfaces must also meet the requirements of the nick-break test. The two root-bend coupons can show no sign of a fracture until the coupon has been bent through at least 90 deg. After bending the coupon through 135 deg, a crack exceeding $^1/_8$ in. in any direction is cause for rejection. The remaining two coupons are subjected to a nick-break test. This test is designed to determine the soundness of the weld. The sides of the coupons are nicked in the center of the weld with a $^1/_8$-in. deep saw cut, as shown in Fig. 9. A fracture is then initiated at these saw marks by continuously bending the coupon in opposite directions. To be acceptable, the fractured surfaces must be free from slag or other impurities. Gas pockets are acceptable provided they do not exceed six per square inch of weld metal and that none exceeds $^1/_{16}$ in. in size.

Four side-bend coupons are taken from the completed weld when testing welds in pipe 0.625 in. and greater. One coupon is taken from the top and bottom and one from each side, as shown in Fig. 7. After bending, any crack that has opened up more than $^1/_8$ in. in any direction is cause for rejection.

Branch-Connection Welds

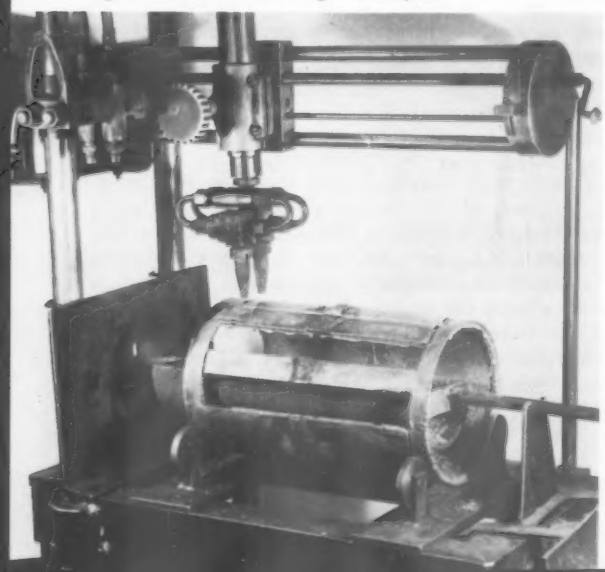
The soundness of the welds is determined by destructively testing the completed branch-connection welds. Coupons are removed and fractured as shown in Fig. 10. The fractured surfaces must meet the same requirements as the butt-welded nick-break coupons.

Test Results

If a contractor welder fails to qualify and the welding instructor feels that the welder has the ability to pass the test, an immediate retest may be made. If the welding instructor feels that the welder needs further training or practice, he may be retested after a lapse of one week provided the welder shows evidence of further training and practice.

If the welder passes his qualification tests he is issued a welding permit. This welding permit is issued for a period of one year; however, it is not acceptable if there is a lapse of 90 days between welding jobs on company property. When a con-

Fig. 8—Method of removing test coupons



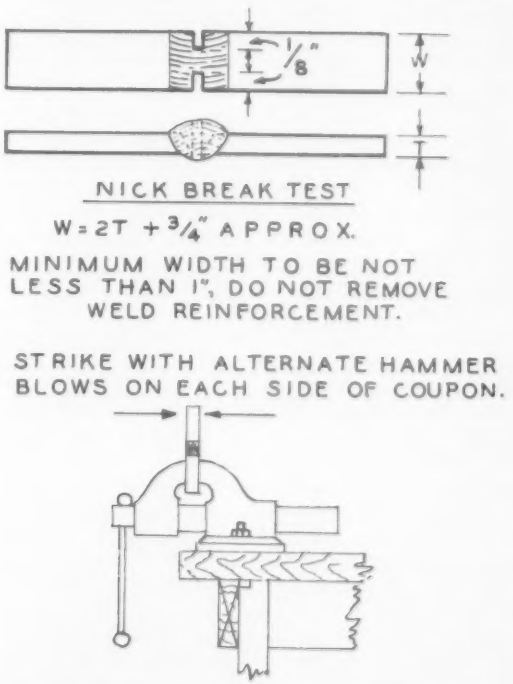

1/8"
W
NICK BREAK TEST
W = 2T + 3/4" APPROX.
MINIMUM WIDTH TO BE NOT LESS THAN 1", DO NOT REMOVE WELD REINFORCEMENT.
STRIKE WITH ALTERNATE HAMMER BLOWS ON EACH SIDE OF COUPON.

Fig. 9—Nick-break coupon and method of testing

tractor welder starts to work on a pipe line, he gives his welding permit to the welding inspector. Normally, the card is returned to the welder when he leaves the job unless he does not perform satisfactorily.

Improving Qualification Requirements

It is not possible to give a welder a test that will guarantee his work in the field. The environment and working conditions are usually much more favorable during the qualification test than those he will encounter in the field. In addition, the welder knows that he is being tested; therefore, the qualification test is merely an indication of what the welder is capable of doing but is no indication of what the welder will do with a production weld.

The ideal test would be to test a weld which the welder has made in the field. This weld would then be a true indication of not only the welder's ability, but also the quality of his work. One method of doing this is to cut a weld from the line and physically test it, but this is quite expensive.

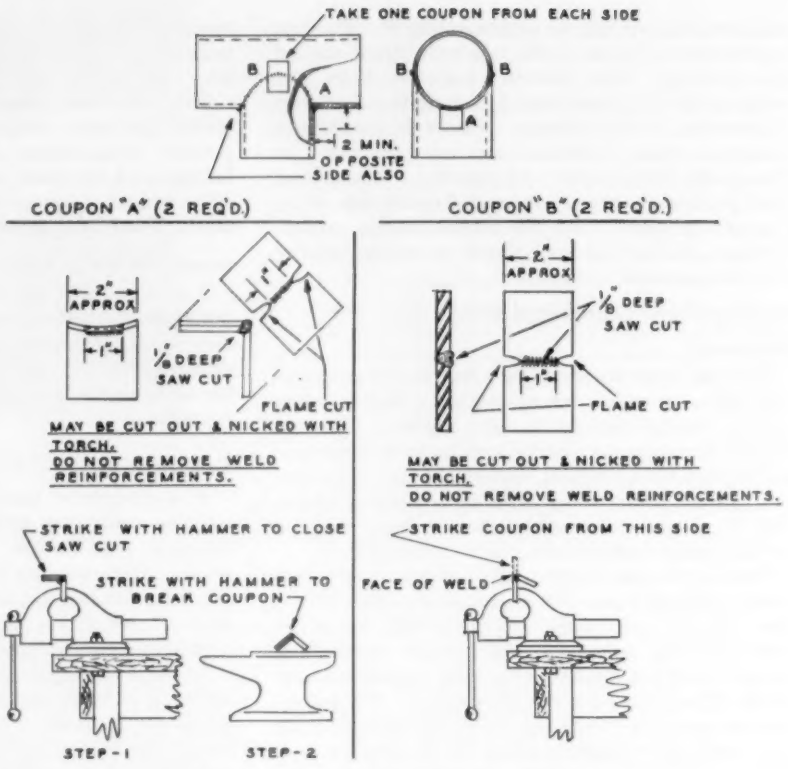


Fig. 10—Testing of a branch-connection weld

It may be feasible to test these welds by some nondestructive method of inspection such as radiographic examination. The defects which are generally found in pipe-line welds and can be controlled by the welder are internal and external undercut, lack of penetration and fusion, porosity and slag inclusions. If the welding procedure is correct, the welder can control these defects. Unfortunately, the nondestructive test cannot be used because there are usually three groups of welders on a construction job. The stringer-bead welders make the root bead in each weld. Immediately following the stringer-bead welders, the hot-pass welders make the second pass. The firing-line welders complete the weld by depositing the filler beads and the cover pass. The number of welders in each gang is determined by the diameter of the pipe. Normally, on 20-in. diam pipe, there would be two welders from each gang welding on the same joint. Therefore, it is possible that five or six welders might contribute to the completion of a single pipe-line weld. This is one of the big problems in the use of radiographic examination for the qualification of pipe-line welders. To complicate matters further, the welders may switch from stringer-bead welder to hot-pass welder and vice-versa. If the welder had been qualified by radiographic examination to make the hot pass, he may not be qualified to make the stringer bead. Another problem is the difficulty of examining a branch-connection weld.

Qualification tests given to welders in any industry are only representative of those welds which the welder will be required to make. Therefore, the method of qualification described in this paper is the best method of qualification which is available today. With the continuance of periodic requalification as well as the use of inspection and nondestructive tests, pipe-line welds are and will continue to meet the desired quality which is so necessary in the pipe-line industry.

Acknowledgment

The authors wish to express their appreciation to S. S. Clair, D. D. Defibaugh and A. A. Taylor, members of the Welding Working Group of the Columbia Gas System for their help in establishing these welder-qualification requirements. We wish to acknowledge the assistance received from members of the Columbia Gas System Service Corp. staff, particularly C. T. Allen and C. W. Churchheus for their capable guidance and assistance in preparing this paper

Corrosion Tests on **Metallized Coatings**

are described and discussed in three-year interim report by AWS Committee on Metallizing. Results indicate that all coatings, regardless of thickness, are giving complete protection to steel base metal

Introduction

In July 1950 the Committee on Metallizing of the AMERICAN WELDING SOCIETY prepared a test and evaluation program covering the corrosion protection of metallized zinc and aluminum coatings, applied to low-carbon steel.

For rural, industrial, salt-air, and salt-spray environments, test panels were 4 x 6 x $^1/_8$ in. Six different locations are in use for these environments. For exposure to sea water at mean-tide and below low-tide levels, 4- x 12- x $^1/_8$-in. panels were made. These panels are exposed at two locations.

Detail and inspection methods were predetermined, with visual inspection being made yearly. One set of panels for each condition is removed at the end of the first, third, sixth and twelfth years for complete evaluation.

There were three major objectives of the program as follows:

1. To determine the life of any given thickness of coating in each environment.
2. To determine the effect of various methods of preparation of the steel.
3. To determine the increase in life of the zinc and aluminum coatings with seal coatings added.

For atmospheric corrosion tests, the zinc and aluminum coatings were applied in the following thicknesses: 0.003, 0.006, 0.009, 0.012 and 0.015 in.

For sea-water immersion, the same thicknesses were used, plus panels having a coating of 0.018 in.

Surface Preparation

Preparation of the surfaces was by blasting with a forced-feed blast generator. Nozzle distance was 7 to 10 in. from the panel and was done at an angle of approximately 90 deg to the surface. Three different abrasives were used: fine silica sand, coarse silica sand and G25 steel grit. In some cases, coatings were applied directly to these surfaces, and in other cases a flash coating of steel was applied to the blasted surfaces before application of the zinc and aluminum.

Metallizing

The metallizing wires used were: zinc, 99.9 minimum purity; aluminum, 99.0 minimum purity; and, steel, SAE 1010 for the flash-bonding coat.

For the metallizing operation, a special automatic machine was built, upon which 36 panels were metallized at one time. There was automatic controlled speed of rotation and traverse of both panels and metallizing gun across the surface, so as to obtain uniformity of metallizing. In the metallizing, each group of 36 panels was mounted in a random fashion on the table of the machine. After one surface of the panels had been given the desired thickness of coating of the desired metal,

Steel boat hull being metallized with zinc

Prepared by Committee on Metallizing, American Welding Society

Fig. 1—Typical exposure rack for test panels

the machine was stopped, the panels reversed in their positions in order to expose the opposite side, and then that side given the desired thickness of the desired metal. In each group of panels, several were weighed before metallizing and these same weighed again after metallizing to determine the weight of coating applied per panel in the group of 36. Subsequent to this weighing, the edges of all panels were given additional coats of metallizing for added protection.

Seal Coatings

Atmospheric Exposure

In addition to the as-sprayed aluminum coatings, a second batch was sealed with a wash primer and one coat of aluminum vinyl, and a third batch was sealed with a wash primer and two coats of aluminum vinyl. Zinc coatings for the same exposure were either bare or with a wash primer and one coat of aluminum vinyl, or two coats of chlorinated rubber.

Sea-Water Immersion

For the mean-tide and below low-tide level, the aluminum panels with sealers were coated with a wash primer and either one or two coats of clear vinyl; and the zinc panels with either one or two coats of chlorinated rubber.

Identification Markings

The maintenance of panel identification is a primary requirement in any corrosion test program. Many systems have been devised and used by many investigators. Experience has shown that notches in the edges of test panels are more suitable than any other type of marking. The number of notches should be kept to a minimum. Code systems for programs involving only a few types of panels in multiple have used certain notches to identify the type and other notches to identify the serial number within the type. The current program

Fig. 2—Aluminum-sprayed atmospheric panels from seven test sites

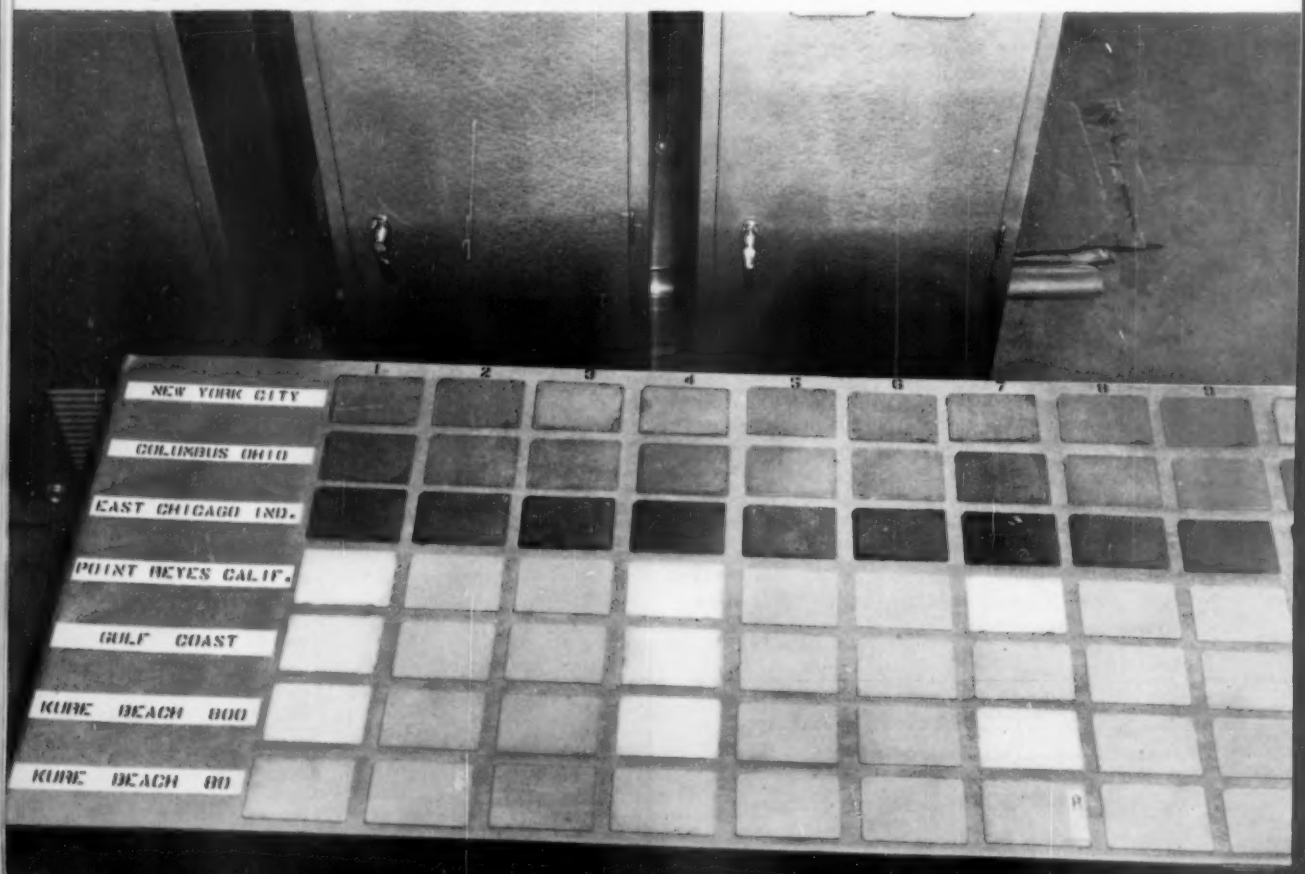


Table 1—Panel-Coating Thickness

Group No.	Magnetic thickness reading, in. average	minimum	maximum	Weight increase (gms) 1	2	3	Thickness by weight, in.
401–436	0.0062	0.0052	0.0070	10.16	10.25	10.18	0.0058
437–472	0.0066	0.0056	0.0076	10.5	10.5	10.5	0.0060
473–496	0.0066	0.0054	0.0071	10.4	11.	11.	0.0062
501–512	0.0066	0.0054	0.0071	10.4	11.	11.	0.0062
513–548	0.0064	0.0058	0.0070	10.5	10.45	10.6	0.0060
549–584	0.0064	0.0056	0.0070	11.	10.7	11.2	0.0062
585–596	0.0063	0.0056	0.0069	10.6	10.35	10.75	0.0061
601–636	0.0064	0.0059	0.0069	10.6	10.5	10.5	0.0060
637–672	0.0063	0.0056	0.0070	10.3	10.35	10.85	0.0060
673–696	0.0063	0.0056	0.0069	10.6	10.35	10.75	0.0061

includes 28 different types of each of two different metal coatings and up to 96 panels in one of the types for each metal.

The notch code system developed for this program is based on the use of consecutive serial numbers. The system is adequate for the numbers 1 to 9999 inclusive and accomplishes full identification by cutting off one corner of the panel to determine orientation, and using a maximum of four notches in any one panel. All notching, of course, was done prior to blasting and metallizing.

Thickness Measurements

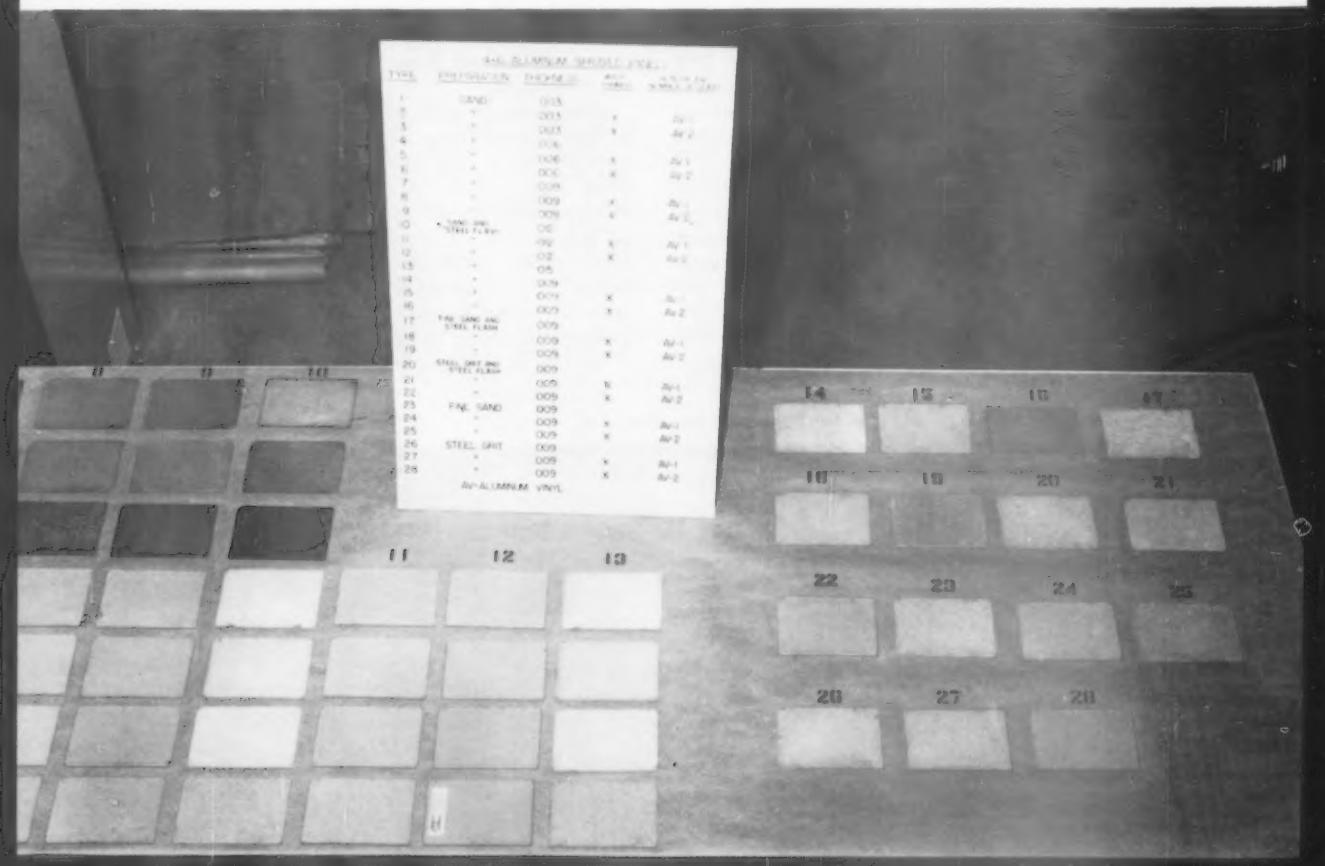
Coating thicknesses on all panels were checked by magnetic thickness gage and by weight increase. Complete records were kept on this subject. Table 1 gives typical data showing uniformity of coating thicknesses on the 4- x 6-in. aluminum panels where the specified thickness was 0.006 in.

Test Sites

The dates when the panels were first placed on exposure at the various test sites are shown in Table 2. Figure 1 illustrates a typical exposure rack on which the panels are mounted.

Test Results

The following is a summary of the condition of test panels as removed from the above sites at the end of 3 to $3^1/_2$ years.



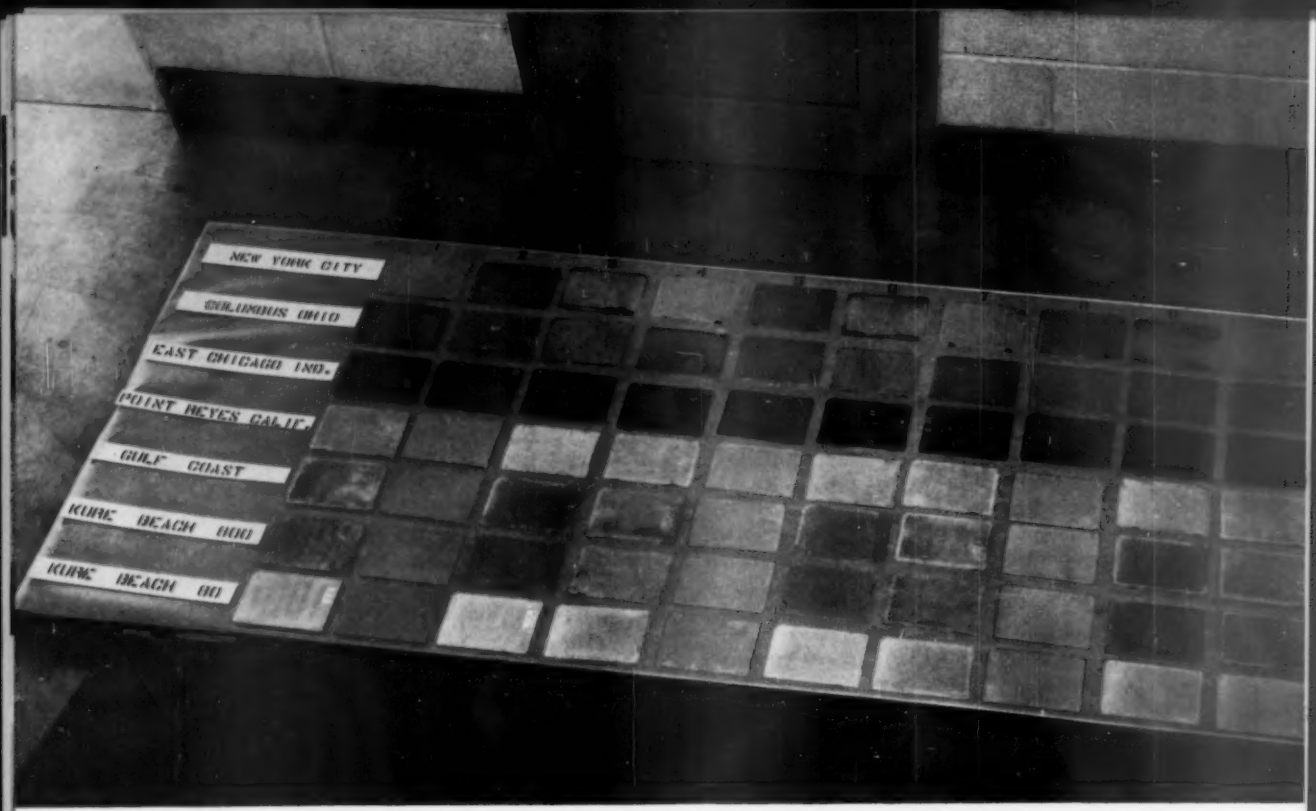


Fig. 3—Zinc-sprayed atmospheric panels from seven test sites

Atmospheric Exposure

All coatings, regardless of the thickness applied or the seal coats, were serving their purpose, namely, the protection of the base steel. For the three-year period, bare zinc and aluminum seemed to provide equal protection to the base. However, the zinc coatings showed more white oxide than the aluminum and this could be expected. Generally speaking, the backs and edges showed more dissipation than the fronts.

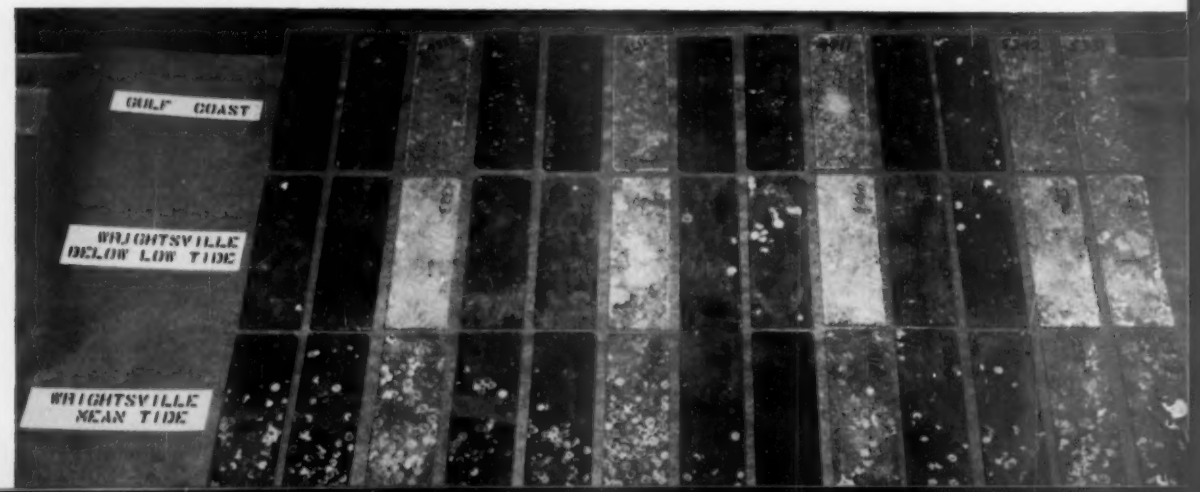
Aluminum-Sprayed Panels. Aluminum coatings with seal coat of wash primer and one or two coats of aluminum vinyl are affording excellent protection regardless of the thickness of the sprayed coatings. The panels with two coats of aluminum vinyl did not collect as much foreign deposit or have as much discoloration as the panels with one coat (see Fig. 2).

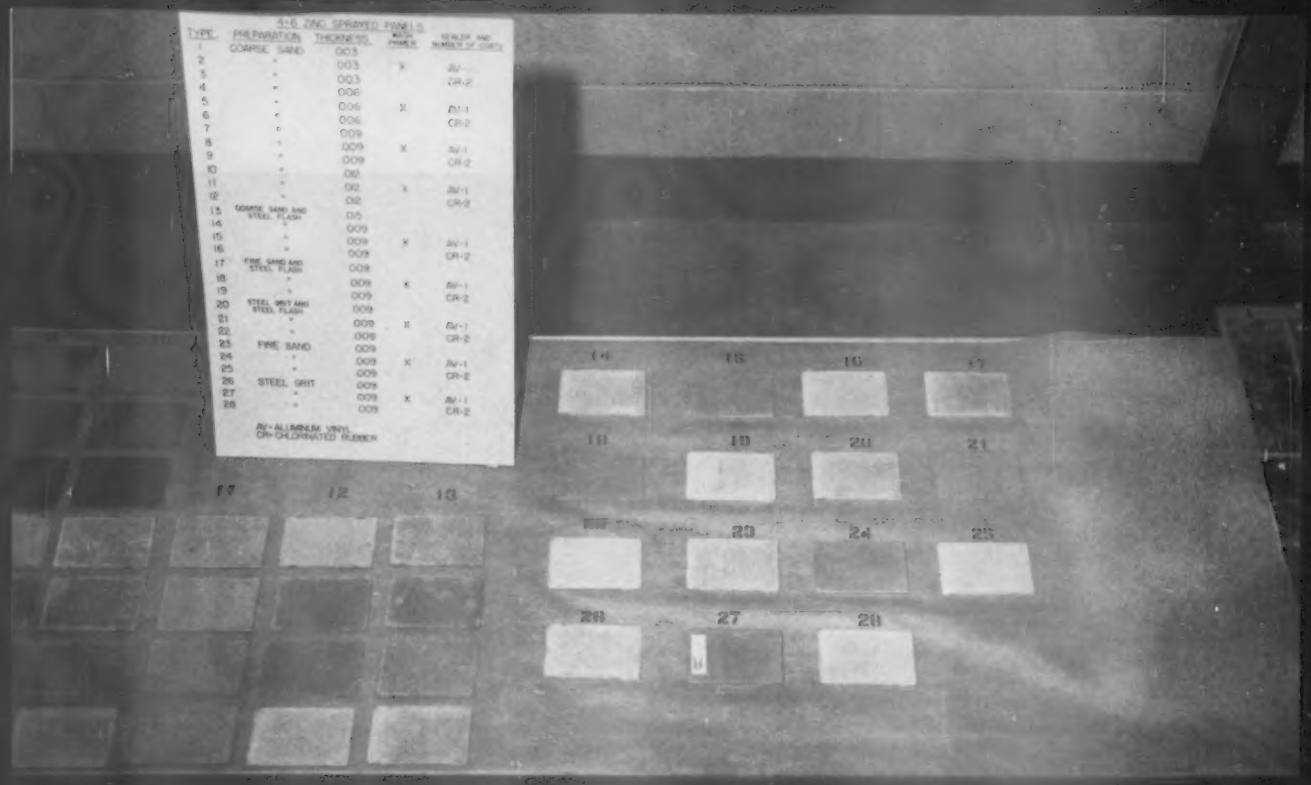
Zinc-Sprayed Panels. Zinc coatings with a seal coat of a wash primer and one coat of aluminum vinyl were also doing a very good job. However, the panels thus treated darkened more than the aluminum panels similarly treated and, in a few instances, showed some localized dissipation of the vinyl top coat.

Zinc coatings with two seal coats of chlorinated rubber showed very little advantage at this time over the bare zinc where the corrosive conditions were more severe (Kure Beach—80-ft location). Where conditions were not as severe, the advantages of this coating on zinc over the bare zinc were a little more pronounced. However, in no case could it be considered good, nor did it compare with the results obtained with the coat of wash primer and coat of aluminum vinyl (see Fig. 3).

At the same time, it would be difficult to point

Fig. 4—Aluminum-sprayed sea-water panels from three test sites





out the advantages of any one thickness of coating over the other. Apparently, the 0.003-in. coating will not last as long as the others, but it is impossible even to hazard a guess as to the life of the others, both coated and uncoated.

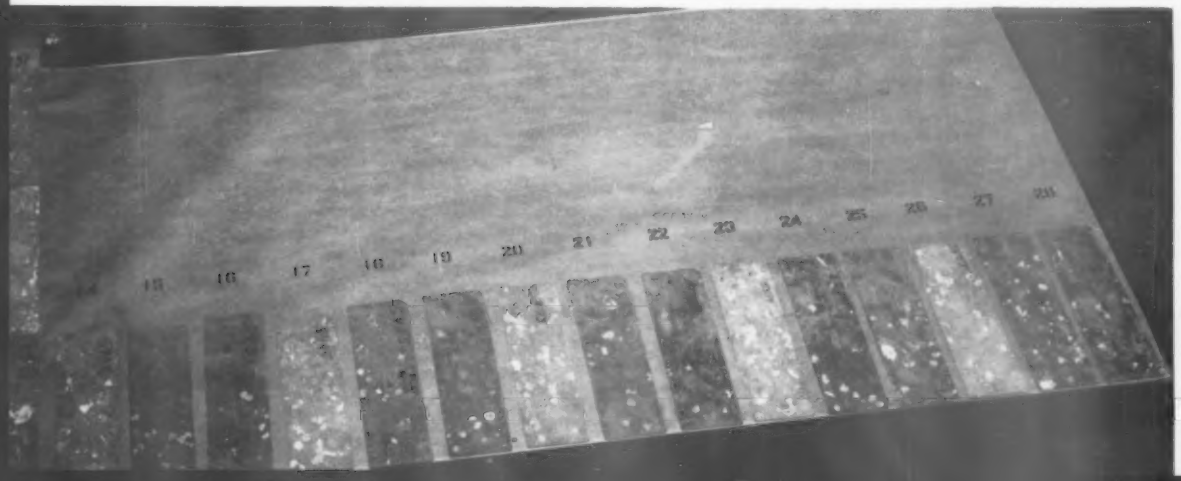
Sea-Water Immersion

Aluminum-Sprayed Panels. Both the bare aluminum panels and those sealed with a wash primer plus clear vinyl continue to protect the base metal. The unsealed coatings show some attack on the aluminum itself, but all sealed panels are in excellent condition. At this time there is no apparent difference betwen one coat and two coats of clear vinyl (see Fig. 4).

Zinc-Sprayed Panels. Bare zinc coatings and those sealed with chlorinated rubber show the same results. The zinc has corroded rapidly. In many

Table 2—Test Sites

Test site	No. of panels Zinc	Alumi-num	Date exposed
ATMOSPHERIC EXPOSURE			
Kure Beach—80-ft location	336	336	Jan. 2, 1953
Kure Beach—800-ft location	156	156	Jan. 2, 1953
Point Reyes, Calif.	156	156	Dec. 16, 1953
Gulf Coast (Brazos River, Tex.)	156	156	March 1954
New York City	120	120	Nov. 10, 1953
Columbus, Ohio	120	120	Nov. 6, 1953
East Chicago, Ind.	120	120	Nov. 9, 1953
4 x 6 reserved	156	156	
SEA-WATER IMMERSION			
Wrightsville Beach, N. C.			
Mean tide	336	336	Oct.-Nov. 1953
Below low tide	156	156	Oct.-Nov. 1953
Gulf Coast (Freeport, Tex.)	156	156	Oct. 30, 1953
4 x 12 reserved	156	156	
Totals	2124	2124	



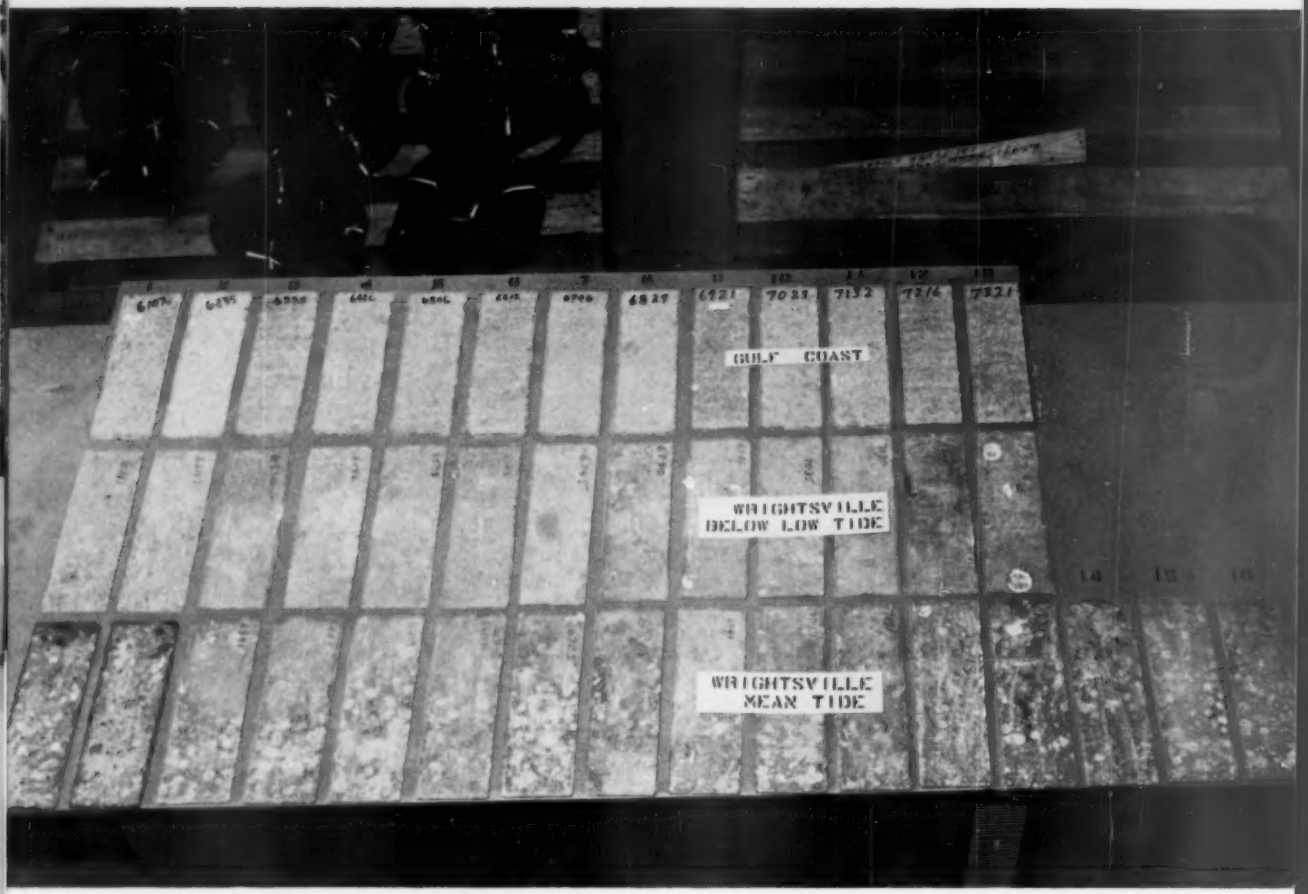


Fig. 5—Zinc-sprayed sea-water panels from three test sites

spots it has dissipated completely and has been replaced by a fairly adherent zinc-corrosion product. This white corrosion product is protective and no rusting of the base has occurred except for a few small spots in the 0.006-in. thick half-tide Wrightsville Beach panels. Affected areas range from about 20% in the case of 0.006-in. coatings, to 1% in the case of coatings 0.012 in. or more in thickness. Coatings sealed with chlorinated rubber show even more damage. In mean-tide exposures, extensive rusting of the base has occurred where coatings were 0.003 in. thick, and rusting is starting on the 0.006-in. panels (see Fig. 5).

It should be remembered that 0.003 and 0.006-in. coatings of zinc are not recommended for such severe conditions. However, these panels were included to obtain comparative data.

Also, it should be noted that this applies to sea water only and that these results may not necessarily apply to fresh water.

Acknowledgment

The Committee extends its thanks to the many companies that contributed to this program, and to the excellent work being done by the field inspection teams. It is expected that a report on the panels removed at the end of six years will be available in 1960.

Appendix

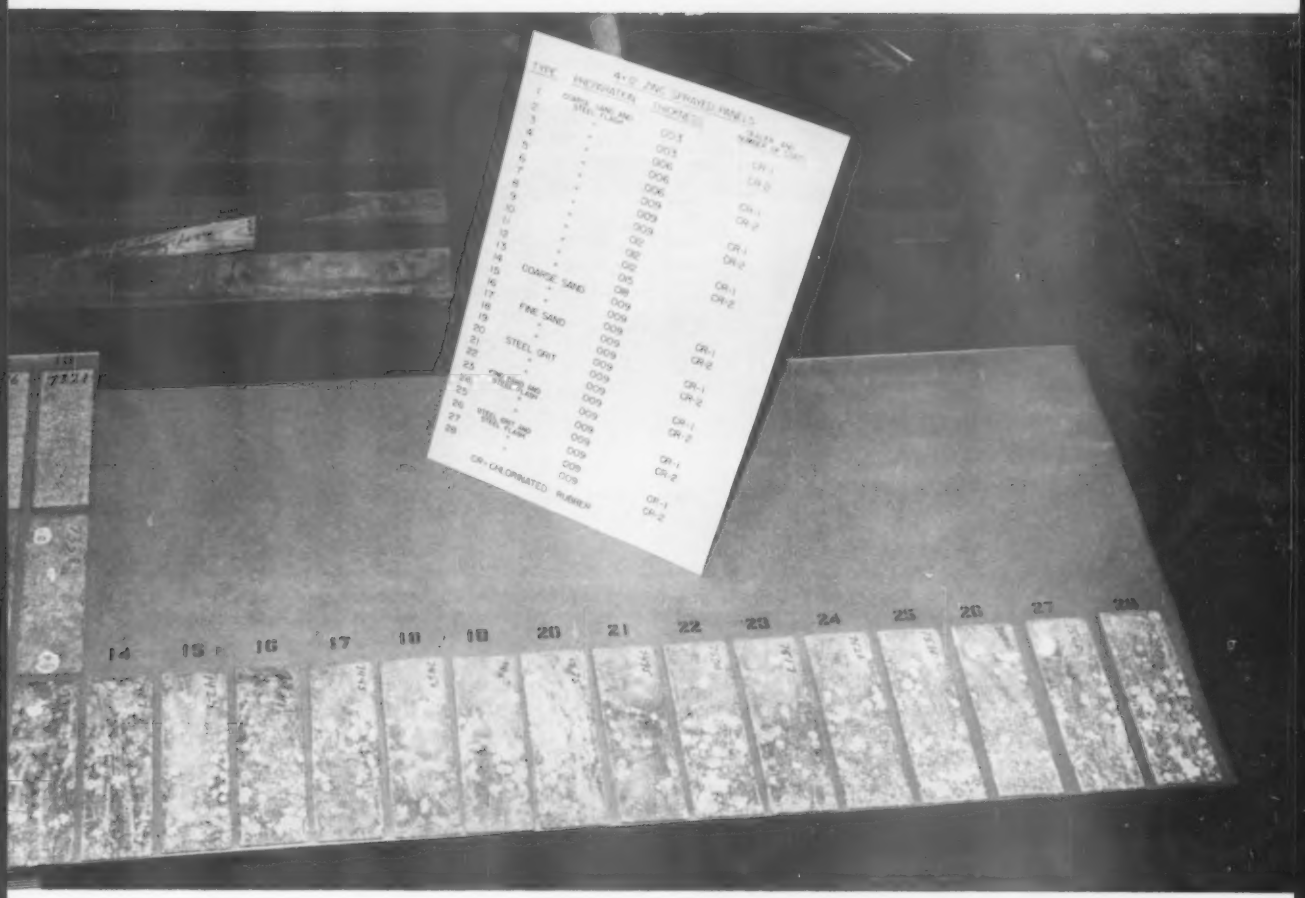
Test Piling

Prior to the exposure of the test panels, some pilings at the Harbor Island test station were metallized and driven.

A report dated June 2, 1958, is summarized as follows:

Piling Driven April 6, 1950

Aluminum-Sprayed. Piling done with aluminum and no sealer shows considerable rusting just below cap sill, partly from rundown of heavy rust from the untreated cap sill, and possibly aggravated by damage due to driving and welding. In the upper $2^1/_2$-ft splash zone there has been some action on the aluminum, but no dissipation and no rusting.



The condition was excellent from the high tide level down as far as could be inspected, which was about 6 in. below the low-low tide level.

Piling coated with aluminum plus an anticorrosive primer has a bare area on the web of about $^1/_2$ sq ft in approximately the mean-tide area. The aluminum has apparently broken away as a result of extensive blistering, and there is some rust but little actual loss of steel. Except for this area, the condition of the aluminum is excellent with no evidence of corrosion of aluminum or steel.

Zinc-Sprayed. Piling done with bare zinc shows that nearly all metallic zinc has corroded away in the upper $3^1/_2$ ft (splash zone) and considerable rust of steel has developed. Immediately below this area, for about $1^1/_2$ ft in the mean-to-high tide zone, the metallic zinc is nearly gone but little rust has developed as yet. Just below this area, there is spotty corrosion of the zinc but no rust. From 1 ft below mean tide on down, the zinc is apparently in good condition.

Piling coated with zinc and sealed with chlorinated rubber shows essentially the same condition as the bare zinc.

Piling Driven July 10, 1952

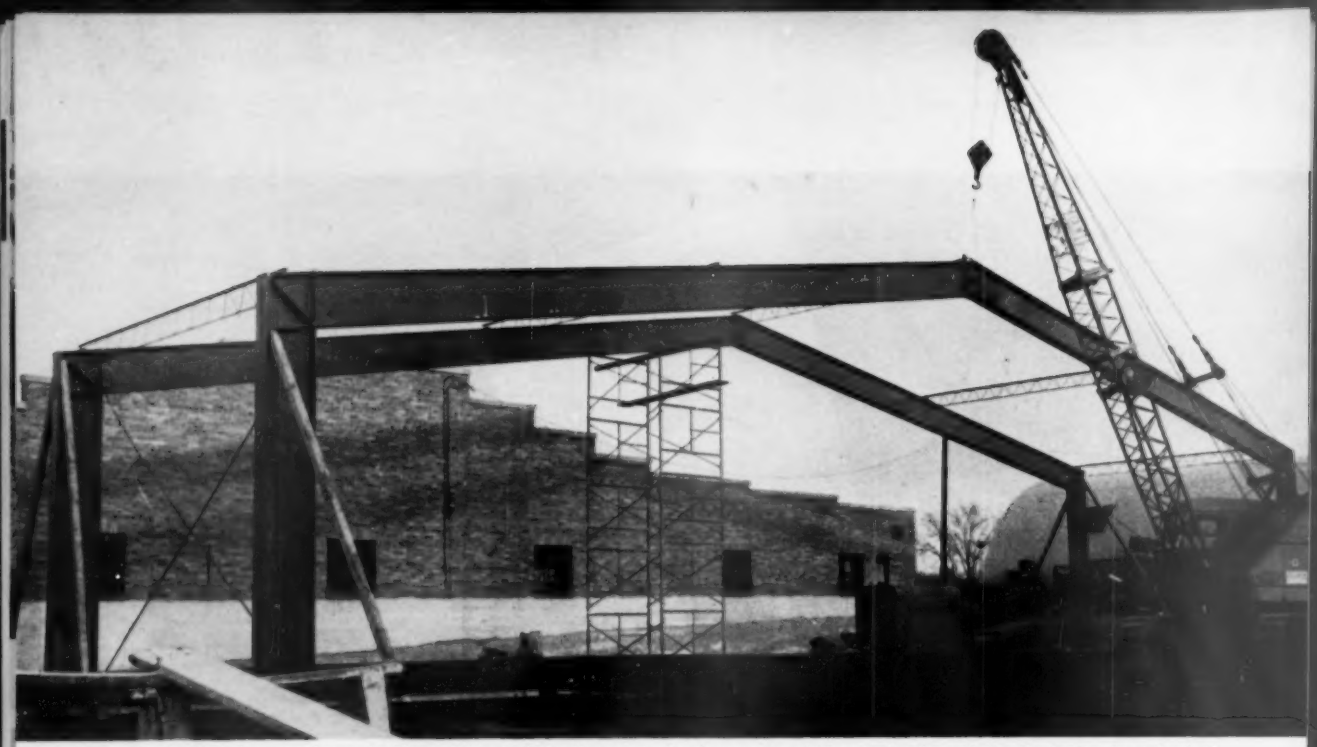
Aluminum-Sprayed. Aluminum plus chromate primer plus two coats of clear vinyl.

Condition of coating is excellent in all areas. This is in spite of the fact that a very light sealing treatment was used. The records show that no primer color was evident a year after the pile was driven.

Zinc-Sprayed. Zinc plus two coats of chlorinated rubber.

The metallic zinc is nearly gone in the splash zone and upper tide zone, with some rusting of steel in the splash zone. In the mean-tide area, considerable spotty corrosion of zinc has occurred and it is estimated that half of the metallic zinc is gone. From 1 ft above low tide on down, the coating appears to be in good condition.

The indications from these tests on actual piling are that the aluminum, plus a primer, plus clear vinyl provide good protection.



The Dalton Co. warehouse in Sioux Falls, S. Dak., is an excellent example of the application of plastic design to a typical single-span rigid frame. Here, frames are being hoisted into position following field welding at site. (Courtesy of AISC)

Plastic Design in Welded Structures

Promises New Economy and Safety

BY CYRIL D. JENSEN

SYNOPSIS. *Plastic design*, being a new method, is given a detailed explanation since it departs drastically from the conventional *elastic-design* methods. Cases described in detail include the fixed beam uniformly loaded, continuous beams uniformly loaded, remarks on the tier-type of office building, and rigid frames of the type used for low factory buildings.

The fields of application for the plastic-design method include continuous beams, one and two story industrial buildings, tier-type buildings and rigid-frame structures intended to absorb bomb blast, collision and earthquakes. Not included are structures subjected to fatigue loading such as railroad bridges.

The limitations necessary to ensure applicability of the plastic-design method include (1) choosing a weldable steel known to be ductile at all temperatures to be encountered, (2) guarding against fabrication processes which might cause embrittlement and (3) designing with care to ensure the full development of the plastic moment at the points where plastic hinges must form, and to ensure adequate rotation capacity by so proportioning the width-thickness ratios that no premature local instability develops.

The discussion of welding details includes (1) the necessary details to assure the absence of notches or "crack starters," (2) the elimination or minimization of costly or unnecessary welding and (3) a discussion of beam-column connections. The discussion of the latter includes a comparison between direct welding of beams to columns and the use of seats and top plates.

CYRIL D. JENSEN is a Professor of Civil Engineering, Lehigh University (on leave of absence as Director of Research & Testing, Pennsylvania Department of Highways, Harrisburg, Pa.).

Introduction—Plastic Design

A new method of designing engineering structures is making its appearance in this country, a method that has already been accepted in England. This new method, *plastic design*, once it is thoroughly understood, holds much promise of effecting more economical structures in those areas where it applies. In effect, this new method permits local overstress at working load provided the structure does not suffer serious deformation and provided there is an adequate factor of safety as regards the ultimate load on the

structure. Before discussing the application of the new method it is necessary to understand thoroughly the design method itself.

Plastic Hinge—Simple Beam. Consider the elementary case of a simple beam being tested under a central concentrated load, Fig. 1. Computations by the elastic theory can only predict the point where the outermost fibers just reach the yield-point stresses. But the beam continues to carry more load, dependent on the shape of its cross section, until the ultimate load is reached. The stress distribution changes from the well-known triangular shape, as in Fig. 1, to approximately a rectangular distribution as shown. The ultimate load can now be predetermined if σ_y (yield-point stress of the steel) is known. The ultimate resisting moment, M_p, for either Section A or B, Fig. 1, is the first moment of the cross section about the neutral axis times σ_y. In the case of an elastic analysis, the resisting moment is given by $\sigma_y S$, where S is the section modulus. The ratio of the ultimate resisting moment, and the elastic limit moment, $\sigma_y S$, is called the shape factor and will be designated as "u."

In plastic design, a new term is introduced called the plastic section modulus, designated by the letter Z. This new term may be found by multiplying the regular section modulus by the shape factor, or computing the moment of the profile area about the neutral axis. Figure 2 gives the shape factors for several sections. For the wide flange sections, the shape factor varies from about 1.11 to 1.23 with 1.14 representing a median value.

Application of Plastic Design to a Fixed Beam In Fig. 3 (A) there is shown the familiar loading and moment diagrams for a fixed beam uniformly loaded. To design the beam for a given load, "w" lb/ft, it is first necessary to multiply the "w" by a suitable factor of safety, F. Thus the limit load is "Fw" lb/ft. The factor of 1.85 has been advanced as providing, for gravity loading, equal safety as that for a simple beam designed by the elastic method. For a combination of wind and gravity loading the factor should be 1.40.

The next step in the design of the fixed beam is to envision the development of the plastic hinges as in Fig. 3 (B). From the moment diagram in Fig. 3 (A), it is clear that, at low loads on the beam, the ends of the beam are stressed to twice that at mid-span. As the loads are increased, the end moments eventually reach their limiting values of the plastic moments as shown in Fig. 3 (B). Now, as the beam load is further increased, no immediate collapse of the beam occurs but rather the deflection slowly increases with the increase in load, the end moments holding steady at M_p, while the mid-span moment increases until it too finally reaches M_p. At that load the third plastic hinge forms (at mid-span) and the ultimate load is reached. Figure 3 (B) shows the beam loaded to its limit, the formation of the three plastic hinges, the moment diagram at ultimate load and, lastly, in (D), the deflected beam (where

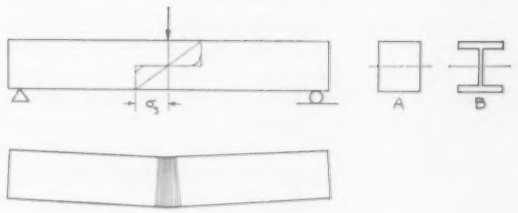


Fig. 1—Plastic hinge—Simple beam

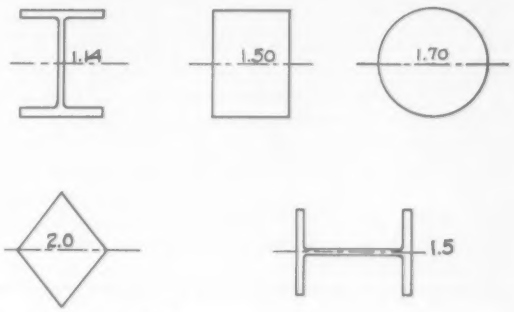


Fig. 2—Shape factors

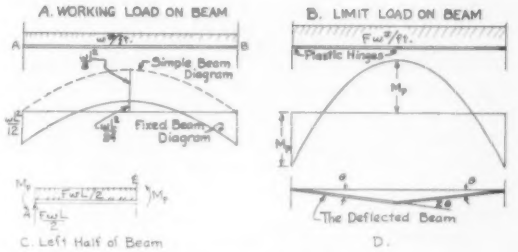


Fig. 3—Application of plastic design to a fixed beam

the elastic deflections can be omitted).

There are a number of methods for computing the required plastic moment, two of which will be given. The first involves nothing but free body diagrams and the laws of equilibrium, while the second utilizes the principle of "virtual displacement."

Solution No. 1. Draw left half of beam as in Fig. 3 (C):

$$\Sigma M_A = 0$$

$$2M_p = \frac{FwL}{2} \cdot \frac{L}{4}$$

whence $M_p = FwL^2/16$.

Solution No. 2—Virtual Displacement. "If a system of forces in equilibrium is subjected to a virtual displacement, the work done by the external forces equals the work done by internal forces." Assume in Fig. 3 (B) that plastic hinges form at the

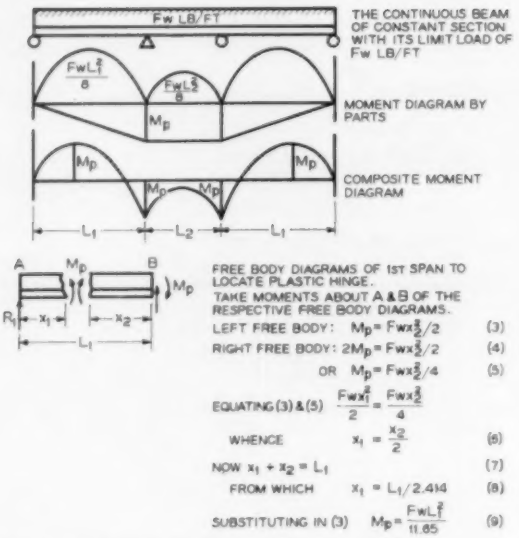

Fw LB/FT
THE CONTINUOUS BEAM OF CONSTANT SECTION WITH ITS LIMIT LOAD OF Fw LB/FT
MOMENT DIAGRAM BY PARTS
COMPOSITE MOMENT DIAGRAM
FREE BODY DIAGRAMS OF 1ST SPAN TO LOCATE PLASTIC HINGE.
TAKE MOMENTS ABOUT A & B OF THE RESPECTIVE FREE BODY DIAGRAMS.
LEFT FREE BODY: $M_p = Fwx_1^2/2$ (3)
RIGHT FREE BODY: $2M_p = Fwx_2^2/2$ (4)
OR $M_p = Fwx_2^2/4$ (5)
EQUATING (3) & (5) $\frac{Fwx_1^2}{2} = \frac{Fwx_2^2}{4}$
WHENCE $x_1 = \frac{x_2}{2}$ (6)
NOW $x_1 + x_2 = L_1$ (7)
FROM WHICH $x_1 = L_1/2.414$ (8)
SUBSTITUTING IN (3) $M_p = \frac{FwL_1^2}{11.65}$ (9)

Fig. 4—Plastic design applied to a continuous beam

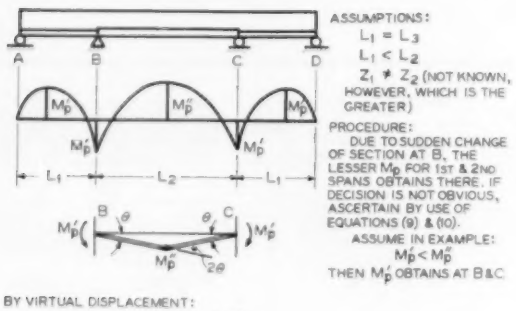

ASSUMPTIONS:
$L_1 = L_3$
$L_1 < L_2$
$Z_1 \neq Z_2$ (NOT KNOWN, HOWEVER, WHICH IS THE GREATER)
PROCEDURE:
DUE TO SUDDEN CHANGE OF SECTION AT B, THE LESSER M_p FOR 1ST & 2ND SPANS OBTAINS THERE. IF DECISION IS NOT OBVIOUS, ASCERTAIN BY USE OF EQUATIONS (9) & (10).
ASSUME IN EXAMPLE:
$M_p' < M_p''$
THEN M_p' OBTAINS AT B&C
BY VIRTUAL DISPLACEMENT:
$2M_p'\theta + M_p''\,2\theta = FwL_2^2 \cdot \frac{L_2\theta}{4}$
WHENCE: $M_p'' = \frac{FwL_2^2}{8} - M_p'$ (11)
DESIGN 1ST SPAN USING (9)
DESIGN 2ND SPAN USING (11)
CHECK: M_p'' IN (11) MUST BE LARGER THAN M_p' FROM (9)

Fig. 5—Continuous beam with different sections for end and middle spans

two ends and mid-span, and that the angular rotation at each end is "θ", as shown in Fig. 3 (*D*). By inspection, the angular rotation at mid-span is "2θ."

Internal work = External work

$$M_p\theta + M_p 2\theta + M_p\theta = FwL \cdot (L/4)\theta$$

Cancelling θ's and collecting M_p's

$$4M_p = FwL^2/4 \qquad (1)$$

whence $M_p = FwL^2/16$.

Having determined that $M_p = FwL^2/16$, the final step in the design is to select the member knowing M_p and the specification (or guaranteed) value of σ_y, which for A-7 steel is 33 ksi.

$Z = M_p/\sigma_y$ (where M_p must be in in.-kips if σ_y = ksi). If w is expressed in lb-linear ft, and L is in ft

$$Z = \frac{1.85\,wL^2}{16 \times 33} \times \frac{12}{1000} = 0.0427\,wL^2 \times 10^{-3}\ \text{in.}^3 \qquad (2)$$

For the specific case of a uniformly distributed load of 50 kip on a 15-ft span, the required Z = 32.0 in.^{3} (from which the required S = 32.0/1.14 = *28.0* and a *12WF27* would be safe). In a similar manner by conventional design methods:

Required simple beam: S = 56.2, use 16WF36
Required fixed beam: S = 37.5, use 14WF30

It may be remarked, in comparing the above three designs, that the same factor of safety exists for the simple beam and fixed beam by plastic design, while the conventional design for the fixed beam has a greater safety factor.

Application of Plastic Design to a Continuous Beam. The design, carried to the determination of M_p, is shown in Fig. 4. By inspection of the composite moment diagram, no greater moments exist elsewhere in the beam; therefore, the solution may be accepted without further checking. Should the end spans be 15 ft and loaded with 50 kip each, uniformly distributed, the required section from formula (9) is

$$S = Z/1.14 = \frac{M_p \times 12}{1.14 \times 33} = \frac{1.85 \times 50 \times 15 \times 12}{1.14 \times 33 \times 11.65} = 38.6\ \text{in.}^4$$

Use 14WF30.

Continuous Beam with Long Middle Span. In this case of a long middle span and relatively short end spans, the exaggerated moment diagram in Fig. 4 is reversed, the mid-span moment in the second span may exceed the maximum moment near the middle of the first span. This is shown in Fig. 5. Assume in this example that no partial length cover plates are to be employed to strengthen the beams at critical points. Under the assumption that the first span

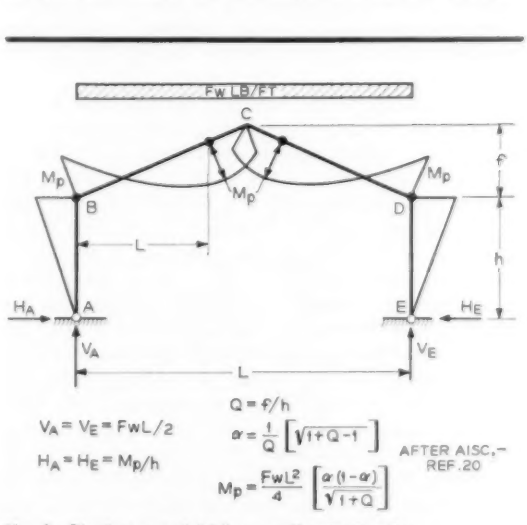


Fig. 6—Single-span rigid frame—Gravity loading

governs the design, formula (9) obtains:

$$M_p = FwL_1^2/11.65 \qquad (9)$$

On the other hand, if the second span governs the design, the problem there is that of a beam with M_p at the ends and M_p at mid-span. In other words the problem is that of the fixed beam problem already discussed in which, from formula (1):

$$M_p = FwL_2^2/16 \qquad (10)$$

The greater of the two M_p's governs the design.

Continuous Beam with Different Sections for End and Middle Spans. The solution for this case is given in Fig. 5. Had M_p'' been less than M_p', in the example, the solution would have been reversed in that M_p'' would have been determined first by formula (10). Then a derivation similar to that for formula (9) in Fig. 4 would have to be made to determine M_p'. The free-body diagram in this figure should be corrected to show M_p' at the break, and M_p'' at B. The revision is as follows:

$$M_p' = FwX_1^2/2 \qquad (12)$$

$$M_p' + M_p'' = FwX_2^2/2 \qquad (13)$$

or

$$M_p' = FwX_2^2/2 - M_p''$$

but

$$M_p'' = FwL_2^2/16 \quad \text{from} \qquad (10)$$

Substituting, and equating M_p's and canceling $Fw/2$

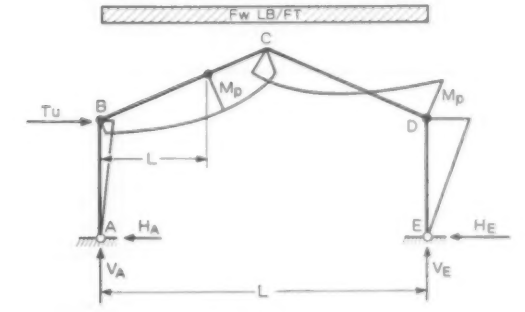
$$X_1^2 = X_2^2 - L_2^2/8 \qquad (14)$$

but

$$X_1 + X_2 = L_1$$

whence

$$X_1 + \sqrt{X_1^2 + (L_2^2/8)} = L_1 \qquad (15)$$



AFTER AISC,–REF. 20

$R_A = \frac{FwL}{2} - \frac{Tuh}{L}$

$R_E = \frac{FwL}{2} - \frac{TuH}{L}$

$H_A = Tu - H_E$

$H_E = Mp/h$

$Q = f/h$

$C = \frac{2Tuh}{FwL^2}$

Tuh = MOMENT OF ULTIMATE HORIZONTAL LOADING TAKEN ABOUT POINT A

(A) (*POSSIBLE CONDITION*)

WHEN $C > \frac{1}{1+Q}$

$M_p = \frac{FwL^2 \cdot C}{4}$

$\alpha = 0$

(B) (*UNUSUAL CONDITION*)

WHEN $C < \frac{1}{1+Q}$

$M_p = \frac{FwL^2}{4}\left[\frac{(1-\alpha)(C+\alpha)}{(1+Q)(1-QC)}\right]$

$\alpha = \frac{1}{Q}\left[\sqrt{(1+Q)(1-QC)} - 1\right]$

Fig. 7—Single-span rigid frame—Gravity plus wind

This can be solved for X_1 by trial knowing that, if $M_p'' < M_p'$, X_1 will be slightly greater than $L_1/2.44$ as found in formula (8). It is possible that the numbers are such that an approximate solution for M_p' can be safely made by use of formula (9), selecting a slightly oversize member, based on the knowledge that formula (9) is slightly on the unsafe side.

As an interesting sidelight, in considering the above problem of different sections for the end and middle spans, is that, at point B, Fig. 5, an advantage accrues if the weaker section is reinforced by short plates, ordinarily only a few feet long, to bring its M_p there up to equal that in the stronger beam. From the examples given it is not felt necessary to detail further the plastic-design procedure.

Rules. From the above examples it becomes apparent that the following conditions obtain:

1. The structure is in equilibrium with respect to the ultimate loads, and thus the rules of equilibrium for any free-body sketch may be used in design or to check the design.
2. The structure, under the ultimate load, is on the verge of becoming a mechanism.
3. The moment produced by the ultimate loading must at no point in the structure exceed the available plastic moment.

Plastic Design Applied to Rigid Frames. Space does not permit a complete treatment of plastic design applied to rigid frames. Briefly, if one is accustomed to elastic-design methods, there are some points of similarity. The pertinent moment diagrams are similar but in the case of plastic design the key moments become M_p. Thus in the case of a single-span rigid frame as in Fig. 6, from elastic analysis it is known that the probable loading to govern the design will be either the gravity loading with F of 1.85 as in Fig. 6 or gravity plus wind loading, with F reduced to 1.4 as in Fig. 7. The plastic hinges are as shown in the figures. A free body of the column reveals M_p at the top end and an axial thrust. This means that, as in elastic design, the column must be designed by an interaction formula.

The time-honored interaction formula is being replaced by the AISC with more accurate formulas dependent on the relative sense of the moments at the ends of the members, which are subjected simultaneously to axial load and moment. For the case of a rigid frame with fixed bases, the end moments on the column have the same sense and therefore try to force the column to bend in an S-curve. Research by Galambos and Ketter[16] indicates the use of the formula:

$$\frac{M_0}{M_p} = 1.18 - 1.18\,\frac{(P)}{(P_y)} \qquad (16)$$

where M_0 is effective end moment reduced from M_p because of axial load, P is the axial load on the column, P_y is the product of the column area and σ_y. For the case of pin-based columns and, therefore, single curvature, and where P/P_y does not exceed 0.15, and where the L/r of the column about the strong axis is less than 60, the plastic moment need

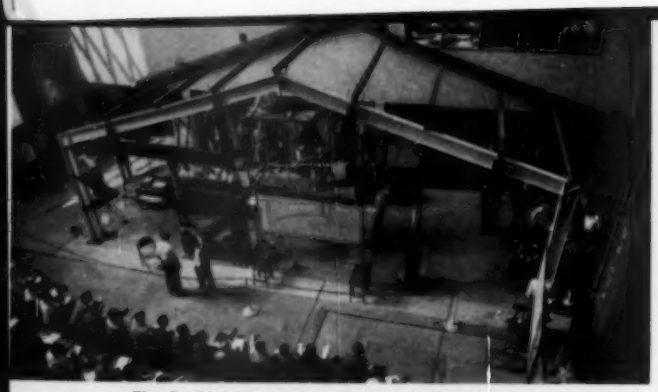


Fig. 8—Rigid-frame test, Lehigh University

not be reduced. In more severe cases, formulas similar to formula (16) are being supplied by the AISC in the form:

$M_0/M_p = B - G\,(P/P_y)$ (Case II, pin-ended at bottom or nearly so) (17)

and

$M_0/M_I = 1.0 - K\,(P/P_y) - J(P/P_y)^2$ (Case III, for moments of opposite sense at ends of the column)

Values of B, G, K and J fluctuate with L/r and are supplied by the AISC. As a generalization, the values of M_0 in formula (17) will be slightly lower than those in formula (16).

Fortunately for the busy designer, charts are appearing from which the pertinent loading conditions can be quickly established and the required M_p's determined with dispatch. Further, the plastic modulus, Z, has been computed for all wide-flange shapes and will soon be available.[20]

The subject of knees in rigid frames brings up some interesting questions. Knees may be indicated for any of several reasons:

1. Architectural effect—the beauty of the curved knee needs no defense.
2. Economy—weight can be saved but at the expense of design time and increased fabrication costs.
3. For field erection with high-strength bolts—an enlarged section such as a triangular-shaped knee provides good space for the necessary bolts and at the same time reduces the required size of the rafters.

An excellent design procedure for rigid frames with knees is given in the new AISC Manual, "Plastic Design in Steel."[20] Space does not permit further details on this subject of knees, but the thought is expressed that the high-strength bolted connection for field erection will make the knee more and more popular. The writer has worked with one company that specializes in "packaged" factory buildings utilizing just such knees. The rigid-frame sections have been neatly designed for downhand shop welding of the component parts, and for field bolting. One of the material cost items saved by this procedure is that of field inspection of the welding.

In general, there are two arguments for the adoption of plastic design: (1) definiteness of the factor of safety and (2) economy. The example already shown of the fixed beam gives an idea of the economy obtained. As regards definiteness of the factor of safety, many tests were made at Lehigh University the past ten or more years in which the agreement between the computed limit loads and the test results were remarkable. One of the tests is shown in Fig. 8, while Fig. 9 shows typical agreement between predicted ultimate loads and the tests. Many more similar correlation tests bear out the ability of this new method to predict ultimate loads.

Applications of Plastic Design

As observed from the examples already shown, plastic design is especially applicable to continuous beams in buildings, including purlins, to one- and two-story rigid-frame-type industrial buildings, to tier-type buildings and generally to structures intended to absorb dynamic loads such as earthquakes, collisions and bomb blast. However, it is important to understand the restrictions or limitations of this new design method. These are described in the following paragraphs.

Materials

This design method is practically restricted to the use of that steel which is readily weldable, which will not fail in brittle fracture, and which exhibits a good range of plastic yielding after first obeying Hooke's law to a suitably high elastic limit. The steel must be resistant to the initiation and propagation of cracks under all service conditions. This is referred to as "notch toughness."

Notch Toughness

Notch toughness is basically a quality of the material selected. Among factors affecting notch toughness is temperature and it can be also changed by improper fabrication procedures. Thus the material may lose its toughness and become brittle. Reference is made to the Three Rivers Bridge failure in Canada for such an example. Fabrication proce-

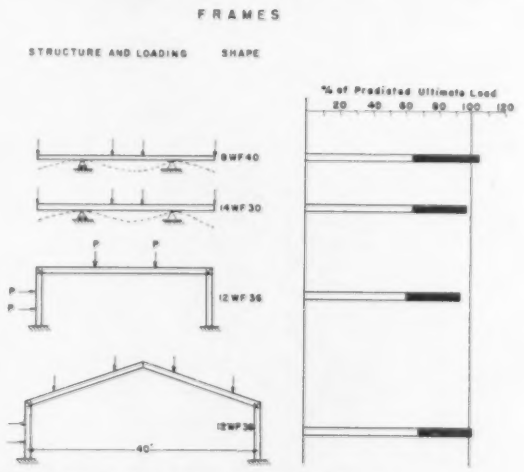


Fig. 9—Correlation between test results and predictions by plastic design

dures may raise the temperature (called the "transition temperature") at which steel becomes brittle. It has been shown that the presence of internal stresses can raise the transition temperature. For example, in butt welding two beams of fully killed steel, the tests showed a transition temperature of −29° F in the "as-welded" condition while on companion specimens, one of which was stress relieved and the other welded with preheat, the transition temperatures averaged −51° F.

It is well known that cold working a steel causes a loss in notch toughness and raises the transition temperature. Tests, where the cold working was done in the laboratory by inducing a fixed amount of prestrain (2, 5 and 10%), showed an appreciable rise in the transition temperature, values of 60-deg rise for a 5% prestrain being common.

Shearing and Punching

Shearing and punching are especially critical both for the cold working at the edges, and the possibility of causing small cracks at the sheared or punched edges which may initiate tearing.

Strain Aging

This is defined as a gradual change in properties occurring as a result of previous cold work. The time rate of change may be slow at room temperature, but may be accelerated by increasing the storage temperature. In fact, a temperature of 400 to 850° F applied to a cold-worked steel can cause an immediate strain aging with a possible raising of the transition temperature to as high as 70° F.

From the above statements concerning cold working and the accelerating effect of 400–850° F it may be concluded that attention to fabrication procedures may pay off in preventing a change in the properties of the steel from one that is tough and ductile to one that may become brittle. Shearing or punching followed by the nearby application of the cutting torch or the electric arc can well cause embrittlement. When welding on sheared edges, the heat of welding raises the cold-worked steel above 1600° F and the entire effect of the cold working is removed. The problems, then, arise from sheared or punched edges which are left exposed and which are subject to sizable tensile stresses.

Stress Concentrations

Plastic design can hardly apply if, at a point where a plastic hinge is expected to form, there is a stress concentration owing to faulty design or fabrication. This phenomenon is well known and only one example is included. In Fig. 10, failure to cope and use a backing plate as in (*A*) may result in a stress concentration and possible crack starter at point *C;* while in Sketch *B failure* to add a small fillet at point *E* may cause a doubling of the stresses at *D* owing to the stress-concentration factor, and if undercutting at *D* has taken place during the welding, the concentration of stress is even more serious.

From a study of the above limitations to the use of plastic design the following comments are offered:

1. If holes are to be provided, drill them or else subpunch and ream to remove the cold-worked material.
2. A sheared edge, if subjected to tension, could easily be the cause of a premature fracture.
3. If welding is along the entire length of a sheared edge, theoretically there is no problem.
4. Do not peen welds—there are too many problems connected with it. Should peening be necessary, at least do not peen the last pass of welding.
5. If the application of heat is used to straighten a structural member, do not water-quench above the martensite temperature (about 600° F).

Local Instability

Plastic design requires that, when the plastic hinge is forming, there be no premature buckling of

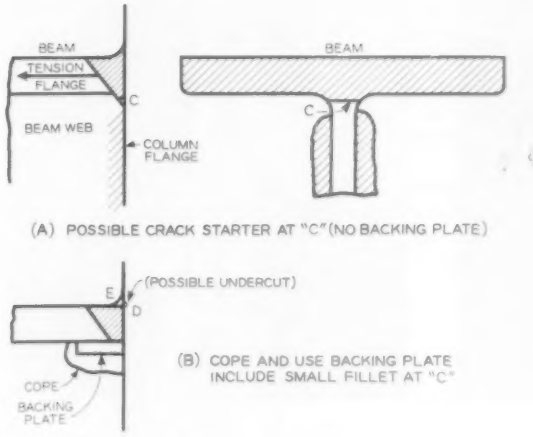


Fig. 10—Examples of stress concentrations

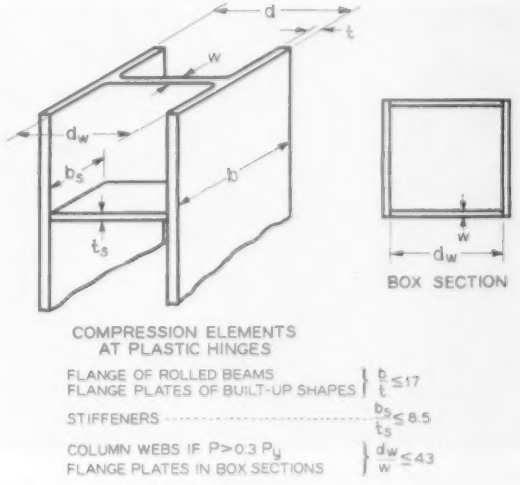


Fig. 11—Prevention of local instability

any of the structural parts. Research at Lehigh University has led to the maximum permissible width-thickness ratios shown on Fig. 11. Keeping the ratios within these limits is insurance that if a plastic hinge were to form because of overload, the hinge would maintain its full M_p through the required rotation angle as successive hinges form to the final ultimate load.

Tier Buildings

The principal problem involving plastic design of tier buildings is in the beam-to-column connections. Many tier buildings have such proportions or are provided with bracing such that wind moments do not enter into the design of these beam-column connections. This condition will be treated first.

The decision must be made, in designing a tier building, whether to cut the beams $^1/_2$ in. clear of the columns and employ a seat-and-top plate type of connection or to cut the beams to exact length and weld directly to the columns. Direct welding, shown in Fig. 12, transmits the stress directly from beam to column, while in the seat-top plate connection the stress is transmitted twice by way of the connecting elements. Since the direct welding employs butt welding at 20 ksi, and the welding on the seat-and-top plate involves fillet welding at 13.6 ksi, the argument can be advanced that direct connections reduce the required welding by over 50%. Later it will be shown that this is not entirely the case if one takes advantages of special techniques in designing the top-plate connections.

The four photographs in Fig. 12 show various means of effecting the connections. Since the objective of the tests was to obtain fundamental information on behavior, seat angles and other erection devices were omitted. Note in (*A*) that the test was made without column stiffeners. Since the full M_p

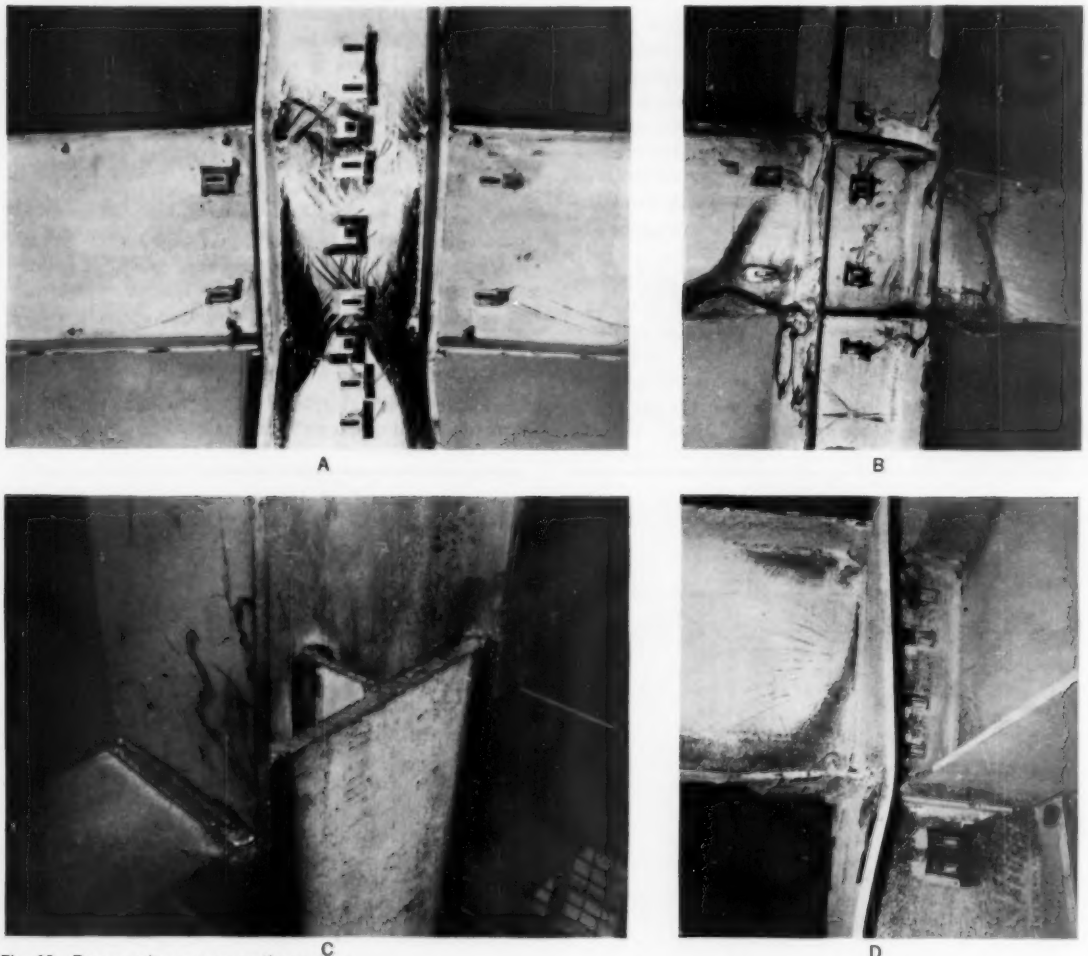


Fig. 12—Beam-column connections

of the beams was not realized in this particular test, it may be inferred that the column web was deficient. In (*B*) and (*C*), stiffening is provided in two different ways. The horizontal plate stiffeners in (*B*) appear to be an efficient way to accomplish the mission of stiffening, but certain problems appear should this be applied to a four-way connection. The vertical stiffening in (*C*) appears to be needlessly heavy but it does have the merit that it is all shop welding and much of the welding could be done by semiautomatic process. It is evident that (*C*) is excellent from the viewpoint of field erection of four-way connections. The four-way connection (*D*) would undoubtedly pose some field-erection problems; erection seats, plates or clips are evidently indicated.

The American Institute of Steel Construction has a criterion in its present specifications for structural steel for buildings to determine if stiffeners are needed. This criterion (Section 26 (h)) states that stiffeners are not required for rolled sections if:

$$\text{(For interior loads)}\ \frac{R}{w(t + 2k)} = \text{not over 24 ksi}$$

This criterion has been found to be too conservative, and a revised formula is under consideration. As a temporary measure, the $2k$ in the above formula can be changed to $5k$; then, since t is usually less than k, the formula can be simplified on the conservative side to:

$$R/6kw \leq 24 \text{ ksi}$$

Should a column web be found too thin by this criterion, the stiffeners must be designed to make up the deficiency. It is assumed that, if a stiffener is added to prevent web crippling, a similar stiffener will be placed in the column web opposite the beam tension flange.

No official criterion is presently available to determine the necessity for stiffeners opposite the beam tension flanges. It has long been known that higher stresses exist in the butt welds of unstiffened connections at the middle of the welds, but tests at Lehigh University have consistently shown the tension side stronger than the compression side. The counter argument is that a failure of the tension weld would possibly be catastrophic in its effect, and thus the tension weld rates a higher factor of safety. Until a criterion is available, it is suggested that the above modified crippling formula be used for both tension and compression sides and that stiffeners be employed in all doubtful cases.

For the case of beams framing to columns and causing unbalanced moments at the connection, a check is required on the ability of the column web at the connection to carry this unbalanced moment. The AISC, in Ref. 20, presents a formula for the required web thickness, w, as follows:

$$w = \frac{0.60M}{A}$$

where M is the algebraic sum of clockwise and counterclockwise moments applied by members framing to opposite sides of the connection web boundary in *k*-ft and A is the area of connection web (out-to-out of flanges or stiffeners).

Example: Is web reinforcement needed at the interior connection shown in Fig. 13? Algebraic sum of moments on opposite sides of joint:

$390 - 200 = 190$ or $150 + 40 = 190$ *k*-ft

For 14WF43, $w = 0.308$ in.

For 21WF62, $w = 0.40$ in.

$$\text{Required } w = \frac{0.60 \times 190}{14 \times 21} = 0.39 \text{ in.}$$

Run 21WF through joint without reinforcement.

The design of the beams for direct welding, with no wind moment to be considered, is accomplished by formulas (1) and (9). Formula (9) would apply to a beam framing between an interior and an exterior column if it were desired to provide a flexible, or shear, connection to the exterior column.

Formula (1), $M_p = FwL^2/16$, seems so daring if one has previously used the simple-beam formula, $wL^2/8$, that a computation of deflection is included herewith for the 15-ft span beam with a 50-kip load for which a 12WF27 was found satisfactory.

PROCEDURE:

1. Establish the first and last hinges to form.
2. Sketch the elastic curve. The elastic curve will be smooth and continuous except at the first hinges to form, where there will be additional hinge angles.
3. Using area-moment method, draw tangent to elastic curve at mid-span; project to left or right support and take moments about A or B of the intervening areas.

$$\text{Deflection} = \frac{L^2}{EI} \times \frac{5}{48} \times \frac{FWL}{8} - \frac{M_p}{8}$$

$$= \frac{180^2}{30{,}000 \times 204} \times \frac{5}{48} \times \frac{1.85 \times 50 \times 180}{8} - \frac{1252}{8} = 0.32 \text{ in.}$$

The computed deflection for the corresponding simple beam, a 16WF36, is

$$\Delta = \frac{5}{384} \frac{FWL^3}{EI} = \frac{5 \times 1.85 \times 50 \times 180^2}{384 \times 30{,}000 \times 446.3} = 0.53 \text{ in.}$$

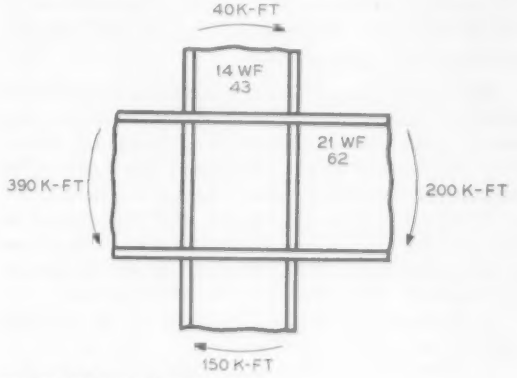


Fig. 13—Web reinforcement

For those who prefer the top plate and seated type of connection, reference is made for design procedures to a paper: "Welded Top Plate Beam-Column Connection" by R. Ford Pray and the writer.[21] However, since the present subject is "plastic design," a modification is presented here strictly conforming to plastic-design methods:

PROCEDURE:

1. Select beam sizes that are somewhat conservative. The purpose is to have a mid-span M_p somewhat large so the required end M_p can be smaller and thus reduce the welding. Note that:

$$M_B + M_{\text{℄}} = FWL^2/8 \qquad (18)$$

2. Determine M_B from the above equation where $M_{\text{℄}} = M_p$ of selected beam.
3. Tension in top plate.

$$T = M_B/d \qquad (19)$$

Area of top plate.

$$A = M_B/d\sigma_y \qquad (20)$$

For an example of the above procedure, see Fig. 14. The final selection of the top plate requires some explanation. If one strictly complies with the AISC specifications (Section 1), a flared plate, as in sketch B, Fig. 14, is required, except that the flaring for the box weld may be omitted if the beam flange is so narrow that it does not provide sufficient width for the side welds. The rules specifically state that the welds must not be overstressed, while overstressing of the reduced section of the plate is permitted. On the other hand, some structural welding engineers contend, with reason, that a constant-width plate as in sketch C is perfectly adequate and safe. It is well known that the yield-point stress of the weld metal (in the butt welds) is considerably greater than that of the plate material. Thus, as a condition of overload is reached, the plate stretches at its yield-point stress, causing the first plastic hinge to form. As explained previously, any additional overload causes a redistribution of the moment diagram. As a consequence, the stresses in the butt welds, regardless of the overload, never exceed the yield-point stress of the plate—a value probably in the neighborhood of 10–15 ksi below yield-point stress of weld metal.

Tier Buildings—Effect of Wind

The application of plastic design to a combination of wind and gravity loads in a tier building rates much study and perhaps investigation, and, therefore, this subject will be introduced here only. The subject is scheduled for treatment by the team of researchers at Lehigh University who contributed so much to the acceptance of plastic design. As a temporary expedient, the following design procedure is suggested and believed to be conservative:

1. Assuming no wind, determine M_p by methods already advanced. In this case F is taken at 1.85.
2. Find wind moments by any acceptable procedure.
3. Add wind moment to fixed-end gravity moment ($wL^2/12$ for uniformly loaded beam). Multiply sum by an F factor of 1.4 to obtain required M_p.
4. Compare M_p's in (1) and (3). Use the larger moment to select the beam.

To demonstrate that the above procedure is conservative—an example, taken from the Pray-Jensen paper,[21] is reworked by plastic design using the above procedure. As noted in Fig. 15, a 15-ft span beam is loaded with 50 kips uniformly distributed and a wind moment at each end of 60 kip-ft. Sketches (A) and (B) in the figure show the separate moment diagrams for the gravity load and the wind moments. Sketch (C), the composite moment diagram, shows a maximum working load moment of 122.5 kip-ft which gives a required M_p of 1.4 × 122.5 = 171.5 k-ft. Use 16WF36. Note in this design that only the first plastic hinge is reached and that a considerable increase in either wind moment or gravity load is needed to bring about a true limit load condition, hence the statement that this is a conservative design.

Conclusions

In this paper an endeavor has been made to give a simple, clear picture of "plastic design" and then to show how this new design method applies to structural welding. Welded joints and plastic design are a natural pair, teaming up beautifully to provide strength, economy and toughness. There are a few situations where high-strength bolting may join forces with this team to effect further economies by encouraging shop welding of subassemblies and then field connecting by bolting. In the case of beam-column connections the option was provided of directly welding the beams to the columns or of

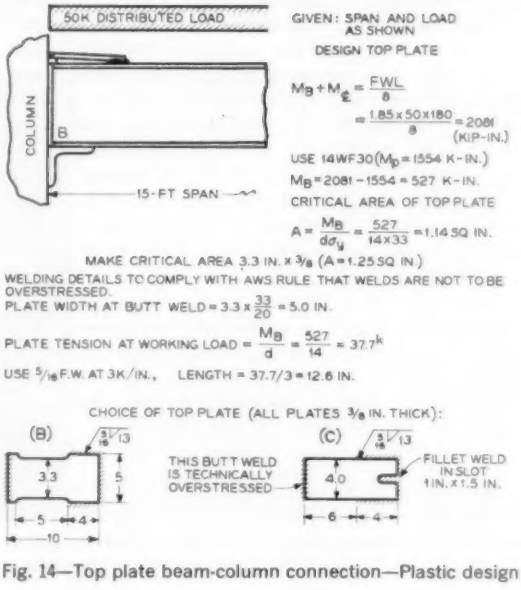

50K DISTRIBUTED LOAD
COLUMN
B
15-FT SPAN
GIVEN: SPAN AND LOAD AS SHOWN
DESIGN TOP PLATE
$M_B + M_{\text{℄}} = \frac{FWL}{8}$
$= \frac{1.85 \times 50 \times 180}{8} = 2081$ (KIP-IN.)
USE 14WF30 (M_p = 1554 K-IN.)
M_B = 2081 − 1554 = 527 K-IN.
CRITICAL AREA OF TOP PLATE
$A = \frac{M_B}{d\sigma_y} = \frac{527}{14 \times 33} = 1.14$ SQ IN.
MAKE CRITICAL AREA 3.3 IN. × 3/8 (A = 1.25 SQ IN.)
WELDING DETAILS TO COMPLY WITH AWS RULE THAT WELDS ARE NOT TO BE OVERSTRESSED.
PLATE WIDTH AT BUTT WELD = $3.3 \times \frac{33}{20} = 5.0$ IN.
PLATE TENSION AT WORKING LOAD = $\frac{M_B}{d} = \frac{527}{14} = 37.7^k$
USE 5/16 F.W. AT 3K/IN., LENGTH = 37.7/3 = 12.6 IN.
CHOICE OF TOP PLATE (ALL PLATES 3/8 IN. THICK):
(B)
3.3
5
5
4
10
THIS BUTT WELD IS TECHNICALLY OVERSTRESSED
(C)
4.0
6
4
FILLET WELD IN SLOT 1 IN. × 1.5 IN.

Fig. 14—Top plate beam-column connection—Plastic design

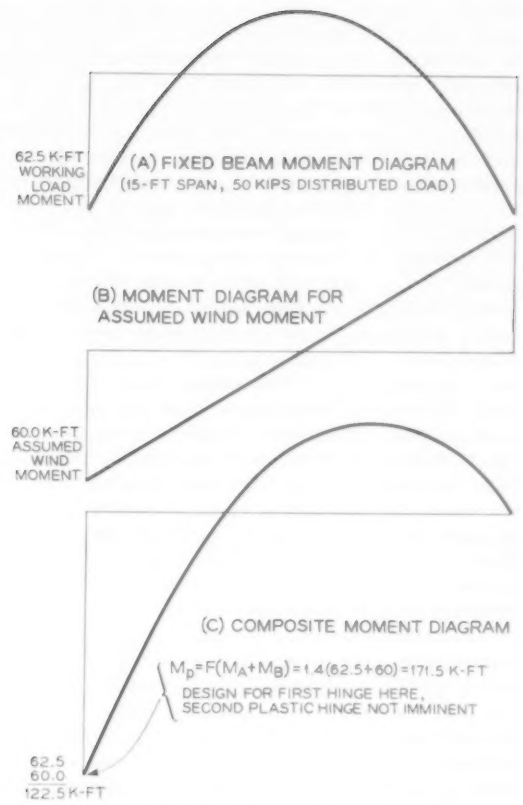


Fig. 15—Conservative design for gravity plus wind

using the top plate and seat type connection. In this latter case, the field welding is kept to a minimum by selecting a beam slightly oversize by plastic-design standards but very economical by elastic-design standards and thereby requiring but a modest size of top plate for the end connection and but a modest amount of welding. The decision of which type of connection to use rests with the designer and depends much on the fabricator's equipment. And lastly, in the case of tier buildings where both wind and gravity loads must be considered, a conservative design procedure—but still economical by elastic-design standards—has been advanced for use in the interim until new studies yield more exact methods.

Acknowledgment

The author is appreciative of the research work in *plastic design* carried out at Fritz Engineering Laboratory, Lehigh University, over the past years and has made copious use of the results of this work.

This work has been supervised by Professors Lynn Beedle, Bruno Thurlimann and Robert Ketter, and includes researchers as listed in the "References." Professor W. J. Eney is Director of the Laboratory.

Appreciation is expressed to the AISC, of which T. R. Higgins is director of engineering and research, with E. R. Estes, Jr., as research engineer, for permission to present material from AISC publications.

For the section on "Tier Buildings" use has been made of the research on "welded interior beam-column connections" at Lehigh University, sponsored by the AISC and directed by a committee consisting of Lynn Beedle, E. R. Estes, Jr., T. R. Higgins, C. L. Kreidler, Heath Lawson, Jonathan Jones (Advisor), with F. H. Dill as Chairman.

Lastly, especial appreciation is expressed to Dr. Beedle and to Carl Kreidler for their constructive comments in preparation of this paper.

Nomenclature:

- b = width of flange of WF section.
- b_s = width of stiffener plate.
- d = depth of WF section.
- d_w = unsupported depth of web section shape factor.
- F = load factor, or ratio of ultimate load to working load.
- L = length of beam.
- M_p = plastic moment of a WF section.
- P = an axial column load.
- S = elastic section modulus.
- Z = plastic section modulus.
- t = thickness of flange of WF section.
- t_s = thickness of stiffener plate.
- w = column-web thickness.
- w = beam load in kip per ft.
- W = total distributed load on a beam span.
- X = a distance.
- σ = unit tensile or compressive stress.
- σ_y = yield-point unit stress.
- θ = angular rotation.

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Fig. 1—Common type of assembly in which gap change is a problem—a brass tube to be brazed into a steel socket

Predicting Gap Change Reduces Trial Runs In **Brazing** Dissimilar Metal Joints

Calculations cannot be used to select exact clearance required, nor do they eliminate trial brazes entirely, but they do permit some useful predictions about what will happen to the initial clearance when parts are heated to brazing temperature

BY D. C. HERRSCHAFT

During a brazing cycle, the parts being joined expand while they are being heated and then attempt to return to their original dimensions when the assembly cools down. When all parts of the assembly are made of the same metal, they change dimensions at the same rate (assuming equal heating and cooling rates) so that the joint clearance remains constant during the entire cycle. However, when the assembly contains dissimilar metals, the joint clearance may change substantially from room temperature to brazing temperature. Figure 1 shows a very common joint configuration—consisting of a tube (or rod) brazed into a socket—in which differential expansion may be particularly troublesome. In such a joint, if a high-expanding metal surrounds a low-expanding metal, the clearance, which was nominally correct at room temperature, may become so enlarged at brazing temperature that the filler metal cannot fill the joint gap. Conversely, if the high-expanding metal is on the inside, the clearance at brazing temperature may be reduced so much that the small amount of alloy drawn into the joint is either ruptured or highly stressed when the gap tries to enlarge again as the assembly cools to room temperature.

When joining dissimilar metals, it usually has been necessary to braze several sample joints having different initial clearances to determine which clearance will produce the most satisfactory joint. Much of this trial and error can be eliminated by some simple preliminary calculations. Although these calculations cannot be used to select the exact clearance required, nor do they eliminate trial brazes entirely, they do permit some useful predictions about what will happen to the initial clearance when the parts are heated to brazing temperature. The calculations will show whether the gap will expand or shrink and the approximate size of the change. From this information one can surmise whether the gap will be too large or too small to be brazed successfully and how much the alloy will be stressed if the gap tends to expand on cooling. The calculations will therefore help in selecting the initial clearance that will avoid excessive stress on the solidified brazing alloy.

The amount of stress the filler can safely withstand is difficult to predict because it is influenced by the ductility of both the base metals and the filler itself. However, as a rule, the layer of filler metal in a brazed joint should not be stretched much beyond 50% of its original thickness. In the examples accompanying these calculations, the objective is to select a room-temperature clearance between the dissimilar metals so that the calculated gap expansion on cooling will cause no more than a 50% theoretical elongation in the layer of filler metal. Theoretical elongation assumes that all the elongation occurs in the filler and none in the base metals.

Formula for Estimating Clearance Change

Let us now derive a general expression for the ef-

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fect of temperature on the joint clearance.

T_1 = room temperature, ° F.
T_2 = solidus temperature of the brazing filler metal, ° F.
ΔT = $T_2 - T_1$.
α_1 = mean thermal expansion coefficient of the male member over the temperature range ΔT, in./in./° F.
α_2 = mean thermal expansion coefficient of the female member over the temperature range ΔT, in./in./° F.
D_1 = outside diameter of the male member at room temperature, in.
D_2 = inside diameter of the female member at room temperature, in.
ΔD_1 = change in the diameter of the male member when heated to temperature T_2.
ΔD_2 = change in the diameter of the female member when heated to temperature T_2.

Based on the above definitions and the laws of linear expansion:

$$\Delta D_2 = D_2\alpha_2\Delta T \quad (1)$$

and

$$\Delta D_1 = D_1\alpha_1\Delta T \quad (2)$$

subtracting eq 2 from eq 1

$$\Delta D_2 - \Delta D_1 = D_2\alpha_2\Delta T - D_1\alpha_1\Delta T = \Delta T(D_2\alpha_2 - D_1\alpha_1) \quad (3)$$

$\Delta D_2 - \Delta D_1$ is the change in diametral clearance caused by heating the parts to temperature T_2. (Actually the parts are heated to a temperature somewhat above T_2 during the brazing cycle, but no stress or restraint develops on the brazing filler metal in the joint gap until the filler reaches its solidus temperature.)

Let $\Delta D_2 - \Delta D_1 = \Delta C_D$ = change in diametral clearance.

Then eq 3 becomes:

$$\Delta C_D = \Delta T(D_2\alpha_2 - D_1\alpha_1) \quad (4)$$

Sign Convention

Note that if α_2 is greater than α_1, ΔC_D is positive, but if α_2 is less than α_1, ΔC_D is negative. By convention, a positive sign indicates that the clearance is increasing, and a negative sign indicates a decreasing clearance when the parts are heated to brazing temperature.

To simplify the equation further, let us assume that $D_1 = D_2$, that is, that the parts have no initial clearance at room temperature.

Then eq 4 becomes:

$$\Delta C_D = D\Delta T(\alpha_2 - \alpha_1) \quad (5)$$

where D is a nominal diameter.

The expression (eq 5) derived above is a general one based strictly on the laws of linear expansion. It does not take into account the elastic moduli of the base materials, the values of which definitely influence the magnitude of the residual stresses produced in the brazed assembly. A complete analysis based on the theory of elasticity is exceedingly complex. In most cases the values obtained from the theory of elasticity may be considerably in error, since the materials are likely to behave plastically at the higher temperatures.

Sample Calculations

The situation of most concern is where α_2 is greater than α_1, since this will produce residual tensile stresses in the brazing alloy when the joint cools to room temperature. Whenever possible, these tensile stresses should be avoided by designing the assembly so that the brazing alloy is compressed upon cooling.

Let us now apply eq 5 to a simple problem with actual materials. Suppose we wish to braze a 3-in. diam yellow brass rod (65% Cu, 35% Zn) into a Type 416 stainless-steel plate. Select the initial room temperature clearance that would produce no more than a 50% theoretical enlargement of the joint gap upon cooling down from brazing temperature.

For these materials:

$$\alpha_2 = 6.50 \times 10^{-6} \text{ in./in./° F}$$
$$\alpha_1 = 12.67 \times 10^{-6} \text{ in./in./° F}$$

These values of α_2 and α_1 are mean values from 68° F to 1112° F (20–600° C). Values for most metals and alloys are available in the publications of the Bureau of Standards. The values given in most engineering handbooks are valid only for small temperature ranges.

Let us assume that we will braze this joint with a BAg-3 filler metal, whose solidus temperature is 1170° F.

$$\Delta T = T_2 - T_1 = 1170 - 70 = 1100° \text{ F}$$

$$\Delta C_D = D\Delta T(\alpha_2 - \alpha_1) = (3)(1100)(-6.17 \times 10^{-6}) = -20361 \times 10^{-6} = -0.020 \text{ in.}$$

The result indicates that the diametral clearance will decrease by 0.020 in. when the parts are heated from room temperature to the solidus temperature of the brazing filler metal. Consequently, the initial diametral clearance must be greater than 0.020 in. Otherwise there will be no gap for the brazing alloy to flow into at brazing temperature.

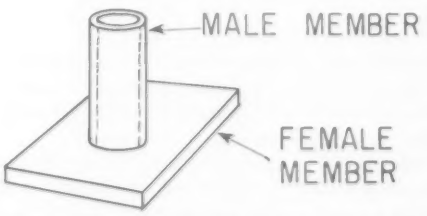

Fig. 2—Typical joint in which differential expansion by joint members made of dissimilar metals can cause an appreciable change in joint clearance during the brazing cycle. When the male member is of the high expanding metal, the joint clearance decreases during heating and increases again on cooling, subjecting the filler metal to tensile stress

Table 1

Diametral clearance		Theoretical percent elongation of filler metal on cooling
At room temperature	At solidus temperature when $\Delta C_D = -0.020$ in.	
0.020	0.000	...
0.030	0.010	200
0.040	0.020	100
0.050	0.030	66.7
0.060	0.040	50
0.070	0.050	40
0.080	0.060	33.3
0.090	0.070	28.6
0.100	0.080	25
0.110	0.090	22.2
0.120	0.100	20

Theoretical percentage of elongation in filler metal for various room-temperature diametral clearances when $\Delta C_D = -0.020$ in. To calculate the theoretical percentage of elongation, divide the absolute value of ΔC_D by the diametral clearance at solidus temperature and multiply by 100.

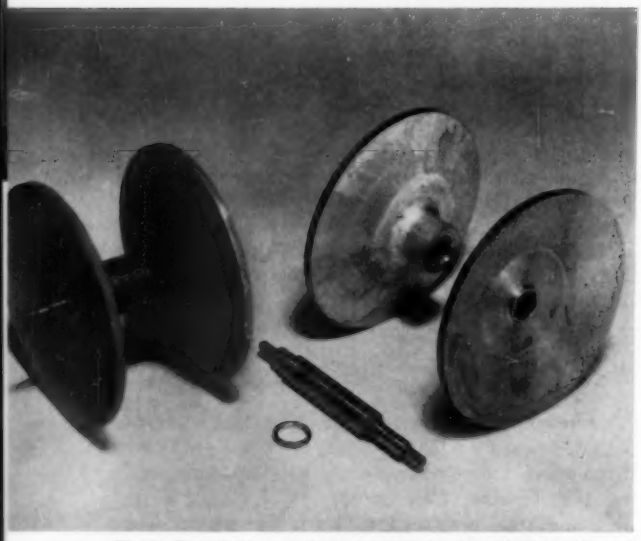

Fig. 3—This fishing reel spool consists of two half spools and a spindle silver brazed together. Half spools are brass forgings; spindle is solid steel. Brazing of these dissimilar-metal parts requires a carefully selected initial joint clearance

How much greater than 0.020 in. should it be? The gap should ordinarily be no larger than needed to produce a theoretical elongation of 50% in the filler metal.

Theoretical elongation is the percent increase in joint gap found by dividing the net change (ΔC_D) by the clearance at solidus temperature. Its value, therefore, depends on the amount of change, ΔC_D, from the starting clearance. This is demonstrated in Table 1 which tabulates the theoretical percentages of elongation when various initial diametral clearances between the rod and plate are reduced by 0.020 in. at brazing temperature. The table shows that, in order to keep the theoretical elongation down to 50%, the parts at room temperature should have a diametral clearance of 0.060 in. (radial clearance of 0.030 in.). In practice such tabulations are unnecessary. The required room-temperature diametral clearance for a 50% elongation is found simply by multiplying the calculated ΔC_D value by 3: in this case, $3 \times 0.020 = 0.060$ in. (For radial clearance divide the result by 2.)

It should be emphasized again that a theoretical percentage of elongation will usually be higher than actually occurs in practice because the base metals also yield somewhat at brazing temperature. Therefore, where the joint gap at brazing temperature is too large to braze satisfactorily, a theoretical elongation greater than 50% might be tried to obtain a correspondingly smaller joint gap at the elevated temperature. In some cases a more sluggish alloy might be used to fill a large gap. If the substitute alloy melts at a substantially different temperature, the new ΔC_D and resulting size of the gap must be recalculated based on the new solidus temperature. However, with certain combinations of metals in the larger diameters, the change in clearance may be so great that brazing the joint might be impractical.

Nomograph Simplifies Calculations

The nomograph in Fig. 4, developed from eq 5, eliminates the necessity for calculating the change in diametral clearance, ΔC_D, for many of the usual combinations of part sizes, metals and brazing conditions. The nomograph is set up on the assumption that the male member has the higher expansion coefficient, i.e., α_1 is greater than α_2. Hence the values on the $\alpha_2 - \alpha_1$ and ΔC_D scales are negative. In cases where α_2 is greater than α_1, the result on the ΔC_D scale should be understood as positive, signifying that the joint gap contracts during cooling, thus compressing rather than stretching the filler metal.

The following example will illustrate how to use the nomograph for finding the ΔC_D for a specific brazing job involving dissimilar metals, and how to use the result to select the initial clearance for the first trial braze (assuming a permissible 50% theoretical elongation during cooling to room temperature).

Given: A $2^1/_2$-in. diam cartridge-brass tube is to be brazed into a carbon-steel plate using a BAg-6 filler metal. Select the room-temperature clearance for the first trial braze.

α_2 (carbon steel) $= 8.61 \times 10^{-6}$ in./in./° F (mean coeff., 75 to 1200° F)

α_1 (cartridge brass) $= 11.60 \times 10^{-6}$ in./in./° F

solidus temperature for BAg-6 = 1250° F (mean coeff., 75 to 1200° F)

Therefore, the working values of the variables are:

D (nominal diameter) $= 2^1/_2$ in.

ΔT (net temperature change in brazing cycle) $= 1250 - 70 = 1180$° F

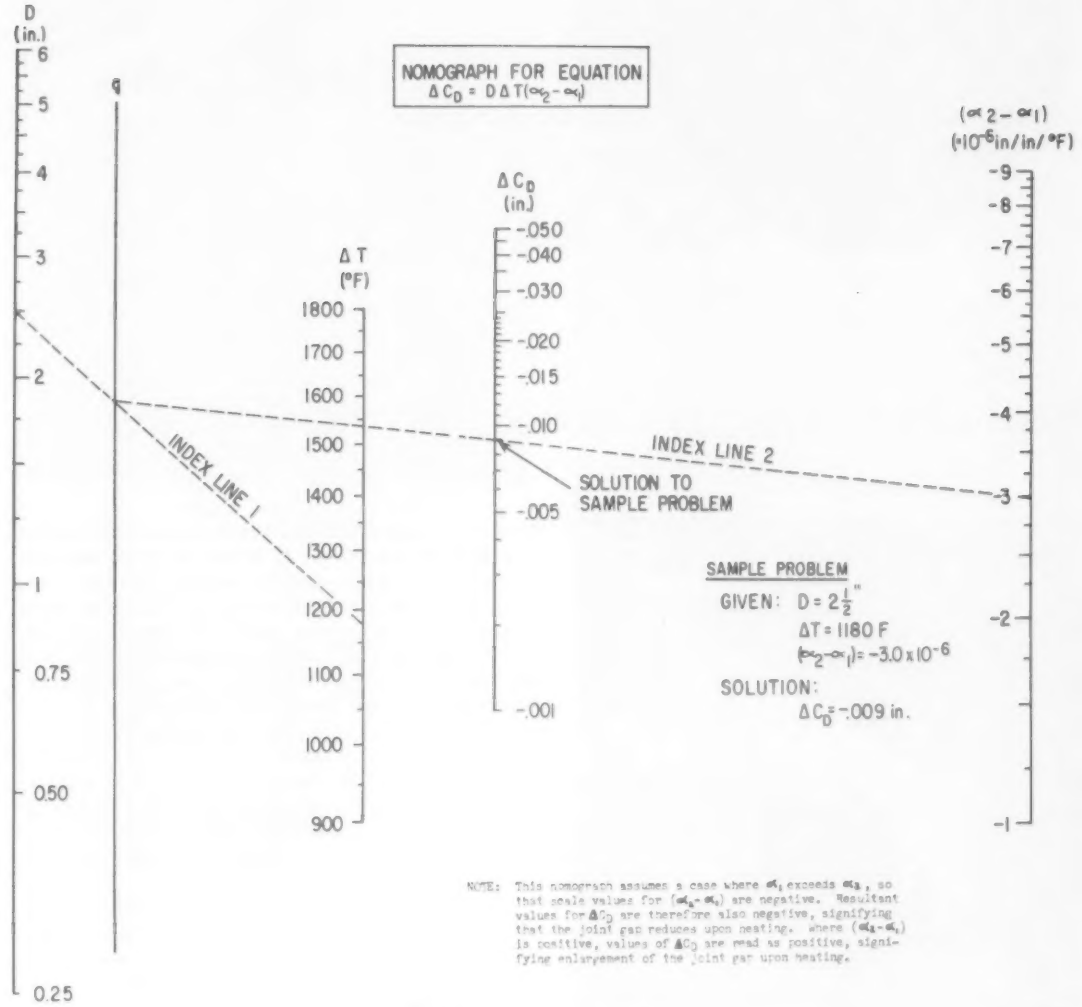

Fig. 4—Nomograph for finding the change in diametral clearance in joints of dissimilar metals for a variety of brazing situations

$(\alpha_2 - \alpha_1)$ difference in expansion coefficients =
$(8.61 - 11.60)\ 10^{-6} = -2.99 \times 10^{-6}$ in./in./° F

Solution:

Step 1: Using Fig. 4, lay off index line 1 connecting the $2^1/_2$-in. value on the D scale and the 1180° F value on the ΔT scale.

Step 2: From the point where index line 1 intersects the q-line, extend index line 2 to the value -2.99×10^{-6} (use -3.0) on the $(\alpha_2 - \alpha_1)$ scale.

Step 3: Where index line 2 intersects the ΔC_D scale, read the resulting change in diametral clearance. The result is -0.009 in., indicating the diametral clearance will shrink by that amount when the parts are heated from 70 to 1250° F.

Step 4: Multiply ΔC_D by 3 to give a 50% theoretical elongation in the filler metal on cooling. A desirable initial diametral clearance = $0.009 \times 3 = 0.027$ in. (or 0.0135-in. radial clearance). This represents a good starting point for the first trial braze.

In cases where the nomograph cannot be read with sufficient accuracy, or one of the variables is off the scale, the value for ΔC_D can be calculated by substituting the appropriate values in eq 5 on which the nomograph is based, i.e., $\Delta C_D = D\Delta T(\alpha_2 - \alpha_1)$.

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Practical Welder and Designer

How to Weld Copper to Stainless Steel and Mild Steel

BY H. B. BOTT

Fig. 1—After beveling both copper and Type 347 stainless steel to provide an 80 deg included angle, $^3/_8$-in. copper specimen is preheated to 1000° F

One of the most difficult dissimilar-metals welding problems is the joining of copper to stainless steel. But it can be done—and successfully too—by using the right technique and selecting the right filler metal.

The need for joining these two very dissimilar types of metals has been on the increase of late with the growing amount of welding in the nuclear-energy fields, and in other specialized applications where it is advantageous to combine the strength and corrosion resistance of stainless steel with the electrical conductivity and/or corrosion resistance of copper.

The procedure or technique illustrated in this article has proved successful in field applications where mild steel, as well as stainless, have been welded to copper.

Table 1 shows the results of a typical test program. Following the welding of a $^3/_8$- × 12-in. specimen of Type 347 stainless steel to copper of the same size, a section was put through longitudinal bend and short-gage tensile tests.

According to test and field reports, equally good results have been obtained using metal-arc, gas-shielded tungsten arc and gas-shielded metal-arc processes. The welding materials used are covered nickel electrode, AWS: A 5.11-54 T (Class E4N11) for metal arc, and nickel wire and rod, for inert-gas-shielded welding AWS: 5.14-56T (Class ERN61).

Joint Design

Joint design for welding of copper to steel follows the same general rules that apply to any dissimilar-metal welding.

The pieces of copper and 347 stainless are first beveled to give an included angle of 80 deg. No

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Fig. 2—Using $^5/_{32}$-in. nickel electrode, welder overlays copper with four overlapping beads. Overlay is run well over edges of bevel

Fig. 3—After $^{3}/_{16}$-in. overlay has been applied to copper, 40-deg bevel is restored. Straight edge is used to assure bevel is even and true

beveling is necessary for thicknesses up to 0.109 in. For materials over 0.109-in. and up to $^{3}/_{8}$ in. a single-Vee joint preparation, having an 80-deg included angle, is recommended. For thicknesses over $^{3}/_{8}$ in. a U or double-Vee joint is preferred. U grooves should have $^{3}/_{16}$–$^{5}/_{16}$-in. root radius and a 15-deg side angle. For J grooves, a $^{1}/_{2}$-in. root radius with a 15-25 deg side angle is recommended.

Cleanliness is highly critical in this operation, so pieces must be cleaned thoroughly after beveling.

The copper is preheated with a torch to 900–1000° F (Fig. 1), and the beveled edge overlayed with four overlapping stringer beads using a $^{5}/_{32}$-in. diam E4N11 nickel electrode (Fig. 2). Each bead should be chipped and wire brushed to remove slag and cuprous oxide. Current should be set at 120–125 amp dc (reversed polarity). Only sufficient amperage to obtain the proper arcing characteristic should be used, to minimize dilution of the overlay with base material. This procedure produces essentially a two-layer overlay, approximately $^{3}/_{16}$ in. thick. Two layers are necessary because dilution in the first layer runs as high as 25%.

Overlay Dilution Low

With two layers of overlay weld metal, the copper dilution in the outer layer is sufficiently low that it does not cause embrittlement in the final welding

Table I

Longitudinal bend test, % elongation	Tensile
$^{1}/_{2}$-in. gage, 20% no failure 1-in. gage, 18% no failure	33,200 psi, broke in copper

Fig. 4—Type 347 stainless steel (left) is positioned with copper to allow root spacing of $^{1}/_{8}$ in. Both ends of joint are then tacked

Fig. 5—Root pass is run in, followed by beads that alternate between sides and middle of root. Current is now 200 amp. Electrode is $^{3}/_{16}$ in. diam

Fig. 6—Chipping out slag and wire brushing, to remove all foreign materials and cuprous oxide, is important to quality of final weld properties

operation. It is important to extend the overlay well beyond each edge of the bevel on the copper to eliminate contact between weld metal and copper during the joining of the dissimilar joint.

After the nickel overlay is applied to the copper and thoroughly cleaned, it should be ground to restore the 40-deg bevel (Fig. 3). A straight edge can be used to determine whether the overlay is true and even.

Next, the stainless steel and nickel-overlayed copper are placed on a copper backing bar, to control penetration, spaced about $^1/_8$ in. apart at the root of the bevel, and clamped into place (Fig. 4).

Using a $^3/_{16}$-in. diam E4N11 nickel electrode, both ends of the joint are then tack welded (Fig. 5). Current should be increased to 200 amp for this operation and for the remainder of the job without preheating. A complete root pass is made next and, after every pass, the weld bead is cleaned by thorough wire brushing (Fig. 6). Beads are laid in on alternate sides of the Vee, and in the middle, in a regular pattern until the Vee is filled (Fig. 7).

During the welding of the Vee, the welder should take care to stay within the area of the nickel-overlay weld metal. Contact with portions of the copper not covered by the overlay causes poor fusion, undercutting and weakening of the weld.

After the final pass, the weld is cleaned, and ground smooth. Typical sections of the specimen taken out for testing and macroexamination are shown in Figs. 8 and 9.

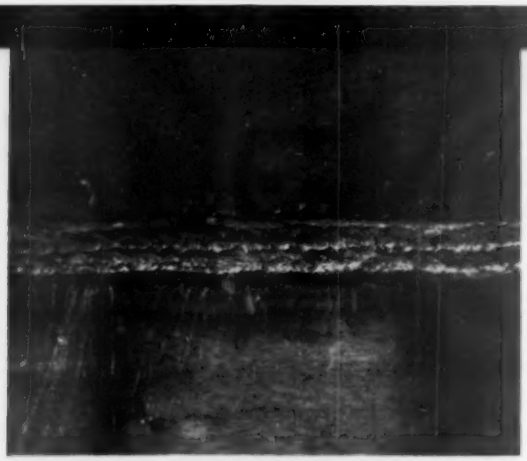

Fig. 7—Close-up of final weld shows even contour, good fusion and penetration. Copper is on the left, 347 stainless steel is on the right

Fig. 8—Cross section of weld, after etching and macroexamination shows no porosity, cracking, fissures or slag entrapment

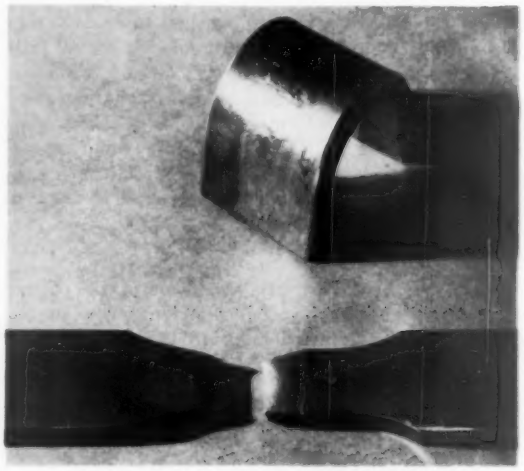

Fig. 9—Longitudinal-bend test proved no failure. Weld is strong and sound. Short-gage tensile test broke in copper at 33,200 psi

Fig. 1—Compressed air-arc torch cutting away a 4- x 4-in. section of cast iron on one of four sides affected by a design change

4000-Lb Iron Castings Salvaged by Compressed Air-Arc Cutting

BY MARTIN G. BOYER

Introduction

Cutting cast iron has until recently been considered difficult and, in some instances, impractical. Several methods are available for cutting through thick sections of iron but these do not permit a fabricator to cut only to a desired depth or dimension, as on a finished casting on which design dimensions are changed. On several types of castings, unwanted metal can be removed by machining. But from a cost standpoint this is not the practical answer when the expense of machining would be greater than the value of the parts being altered, or greater than replacing it with a new part. Still, many iron castings are expensive, especially the large ones. Incorporating changes in design is worth considering when an inventory of obsoleted parts would otherwise have to be written off as a total loss.

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The Problem

The Automatic Transportation Co. of Chicago, Ill., recently faced this very dilemma. This firm is a manufacturer of industrial trucks for handling materials. On one particular model, assembly operations hit a snag. On this truck, the counter balance forms the rear section of the truck body and also houses the engine's radiator. The casting for this unit measures approximately five feet in width, four feet high and almost one foot thick. Each casting

Fig. 2—Finished area on lift-truck counterweight is inspected after modification. Design changes required a larger opening for the radiator

contained 4000 lb of cast iron. Twenty of them were on hand when a design change in the size of the radiator opening made them obsolete. This represented a total value of $6000, an expensive bit of parts inventory to be scrapped. The change in casting design was to accommodate a larger radiator, while the outside configuration and other dimensions of the part remained the same. Company officials realized that the obsoleted castings could be used by removing surplus metal in the radiator grill area to accommodate a larger radiator. Sections about 4 in. thick, 3 in. wide and 30 in. long had to be removed on all four sides of the grill opening. If the castings could not be altered and cut smoothly, they would have to be scrapped. At the same time the work had to be done economically.

Conventional Methods Fail

At first, mechanical cutting devices were used to try to remove the unwanted material. The plan was to drill a series of holes on the inside, one beside the other, all the way around the grill opening. Drilling three inches back from one side, then from a depth of four inches in the other plane, drill in to meet the first series at a 90-deg angle for a depth of four inches. This plan sounded good until tried. But, the cast iron refused to yield to the drill bits. Attempts were made for three days to make the required cutouts by drilling and by oxygen cutting. This began to discourage the idea of trying to salvage the castings. The operations were not only taking an excessive amount of time, but very little progress was being made. In addition, a number of expensive drill bits had been broken and large quantities of oxygen and acetylene had been used.

Solution

The project was almost to the point of being abandoned when it was decided to try an air-arc cutting and gouging torch. This unit uses a carbon or special coated metal electrode to melt metal and a high-velocity jet of compressed air coming through the torch head and aimed directly at the arc point to remove the metal as it becomes liquid. Automatic Transportation used a 400-amp motor generator type welding machine, set at 300 amp straight polarity with $^1/_4$-in. special coated metal electrodes, and 90 lb pressure of compressed air (Fig. 1).

The cutouts were completed in about six hours per casting. Approximately 100 lb of coated metal electrodes were used to make the required cutouts on each casting. After the rough cut was made with this type electrode, the work was "finished" with copper-coated carbon-graphite electrodes which produce a smoother cut or gouged surface than do the metal electrodes. Figure 2 shows salvaged casting.

Acknowledgment

Acknowledgment is made to Don Hausknecht and other officials of the Automatic Transportation Co. and to Jerry Flynn of H. K. Miller, Inc., for their cooperation and assistance in preparing this story.

Submerged-Arc-Welded 48-Ton Sulfate Digester

Dominion Bridge Co. Ltd., Quebec, Canada, recently used submerged-arc welding to fabricate a huge, 48-ton, 54-ft long, $11^1/_2$-ft diam sulfate digester (Fig. 1). The Inconel-clad steel plate was submerged-arc welded at a speed of 12 ipm.

Based on a story by the Linde Co. New York, N. Y.

Fig. 1—Submerged-arc process was used to weld this huge, 48-ton, 54-ft long, $11^1/_2$-ft diam sulfate digester

Welded Atomic-Power-Plant Boiler Containers Are Sealed in a Vault

BY CHARLES W. LYTTON

Fig. 1—The east boiler container of the Shippingport atomic-power station is erected before the concrete vault that houses it. When the tank is completed, the vault will seal it in

Fig. 2—The all-welded container is 97 ft long and 50 ft in diam with $1^1/_4$-in. thick walls. All joints were X-ray inspected with repairs held to $1^1/_4$% of the total footage of welded joints

Atomic-power-station "boiler containers" are huge welded-steel tanks sealed in a thick concrete vault. Inside, concrete walls divide the interior into cubicles. The function of a boiler container is to transfer heat from the atomic reactor to the steam that drives the turbines. They are erected before the vault is complete, then sealed in for life.

The east boiler container at the Shippingport, Pa., atomic-power station is 97 ft long and 50 ft in diam. It is made of $1^1/_4$-in. thick A-201 steel. All joints are welded. Inspection is rigid.

Pittsburgh-Des Moines Steel Co. fabricated and erected the oversize tank. They did as much of the work as possible in their nearby McKees Rocks shop. This included forming all the segments of the shell and attaching the Tee section reinforcing rings that girded the completed shell. They also beveled all the plate edges for welding and actually assembled some of the segments of the tank's hemispherical head. Trucks transported the fabricated parts to Shippingport.

Erection of the boiler container began in a forest of derricks and underbrush of reinforcing rods. Work on the vault was already well underway. As each segment of the container was fit into place, workmen fastened and aligned them with bolt and wedge clamps. Piece by piece, the tank went together until every segment was in place. Then, the welders moved in.

The joints had all been beveled with a 40-deg included angle, leaving a $^1/_8$-in. land. They were fit up with a $^5/_{32}$-in root opening. Bevels on the top of the container were made from the outside, while those on the bottom were on the inside. In this manner, the majority of the welding was done downhand.

Welders used $^3/_{16}$-in. E-6010 electrodes throughout.

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Fig. 3—Inside the tank, clamps hold the segments prior to welding. Joints were beveled from the outside on the top and from the inside on the bottom so that most of the welding was downhand

Fig. 4—After the tank was completed, it was subdivided on the inside with reinforced-concrete partitions. The function of the container is to transfer heat from the reactor to the steam that drives the turbines

They first filled the joint on the beveled side. After back-gouging with a flame torch, they completed welding the back side.

Welding requirements on the job were strict. Joints were 100% X-ray inspected. Only 80 out of a total of 175 welders tested qualified for the job. Careful attention to details paid off, however. Despite inclement weather and other adverse conditions, repairs were held to a meager $1^1/_4$% of the total footage of welded joints.

Less than six months after erection began, the completed tank was being divided into cubicles by reinforced-concrete walls. Soon the vault on the outside was closed. The huge tank was sealed in for a lifetime of service in the nation's first atomic-power station.

Tungsten-Arc Welding Shows the Way

BY A. L. REES

Fig. 1—An operator uses a tungsten-arc torch to join a tubular column for a Florida State Highway road sign

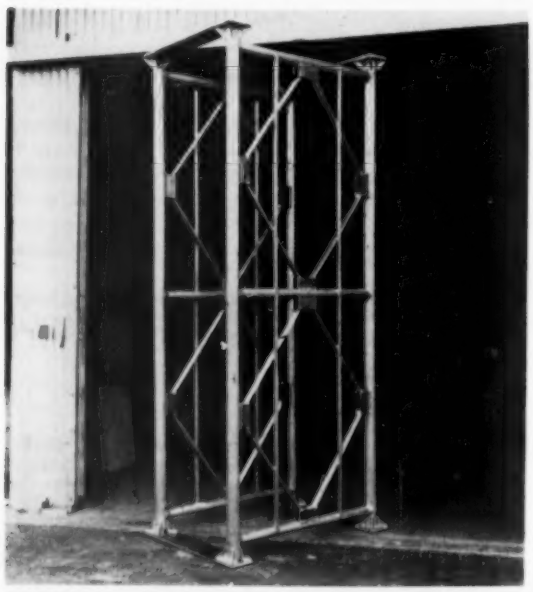

Fig. 2—This completed section of an "over-the-highway" sign carrier is used in single or double lengths, depending upon the length of the sign

A. L. REES is an engineer, Florida State Highway Department Orlando, Fla.

Florida tourists are now being guided to their destinations by gas-shielded tungsten-arc welded aluminum highway signs. The Florida State Highway Department recently designed and developed these low-cost signs.

To date, the Highway Department has successfully fabricated single and multiple sign posts, as well as bridge-type "over-the-highway" spans ranging from 40 to 70 ft in length (Figs. 1 to 3).

These signs were formerly fabricated from steel by a combination welded-bolted design, utilizing covered-electrode welding. In addition to comparatively high production costs, however, the steel signs were expensive both to install and maintain.

Modern aluminum provided the cost solution. The aluminum parts are joined by high-speed tungsten-arc welds that require no postweld finishing—a combination that has substantially reduced production costs. The corrosion-resistant aluminum eliminates the need for painting, further reducing production costs, and *protects itself* against the elements, virtually eliminating maintenance costs. In addition, the lighter aluminum signs are so easy to erect that they have sharply cut installation labor charges.

Signs are fabricated from precut parts made from aluminum alloy Type 6061 3-in. thick channel, $^3/_{32}$- to $^3/_8$-in. thick plate, and $1^1/_2$- to 6-in. diam tubing. R-S5B aluminum rod is used to make all welds, each one shielded from contamination by 99.995% pure argon.

Fig. 3—These weather-resistant signs, tungsten-arc welded from 6061 aluminum, are ready to be installed on Florida highways

Society News

Science of Arc Welding Is the Subject of 1959 Adams Lecture

Plans have been furthered by the AWS Chicago Arrangements Committee to present a program of activites of considerable interest for those who will attend the 40th Annual Meeting and the 7th Welding Show during the week of April 6, 1959. One of the highlights of the week-long convention will be the presentation on Monday morning of the traditional Adams Lecture.

Honoring the founder and first president of the AMERICAN WELDING SOCIETY, the late Comfort Avery Adams, this year's lecturer will be Clarence E. Jackson, staff engineer of the Linde Co. His topic will be "The Science of Arc Welding." Mr. Jackson's lecture will concern the inert-gas-shielded tungsten arc and its use in obtaining basic relationships dealing with volt-ampere characteristics. Data relating to spatter, metal transfer, arc forces and motion will be presented for the inert-gas-shielded metal-arc process. Mr. Jackson will also include a number of observations regarding the mechanics of the arc accompanying the submerged-arc and covered-electrode processes. Spectrographic studies will indicate the effects of atmosphere on arc behavior.

The customary President's Reception will be held in the Bernard Shaw Room of the Hotel Sherman, and will be followed by the annual banquet in the hotel's Bal Tabarin Room. Kurt Stehling, a noted rocketry expert, will address the dining group on what the average citizen can expect in the years to come from the space age.

Two interesting plant tours have been scheduled for Wednesday and Thursday—one will be made of the Dresden Nuclear Power Station and the other will inspect the Combustion Engineering and the Champion electrode plants.

This year's Informal Panel Discussion will concern "Maintenance Welding." It will be held on Wednesday in the International Amphitheatre.

The ladies' program will include such features as a European travelogue, a card party, a theatrical presentation and a guided tour of

1959 ADAMS LECTURER

Clarence E. Jackson will discuss "The Science of Arc Welding" at the opening session of the 1959 AWS 40th Annual Meeting in Chicago on April 6th

AWS DIRECTORS-AT-LARGE

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Junior Past-President	J. J. Chyle		

Chicago's Chinatown. An innovation at this year's convention will be a "get-acquainted" meeting on Sunday evening, which the ladies and their escorts may attend.

Predictions indicate a record attendance of 15,000 at the 7th Welding Show, thereby making the Chicago meeting the largest show ever sponsored by the AMERICAN WELDING SOCIETY. Exposition hours will be from noon to 10 P.M. on Tuesday, 10 A.M. to 10 P.M. on Wednesday and 10 A.M. to 6 P.M. on Thursday.

The quality of the Chicago program is reflected in the balance of the papers selected for presentation, ranging from practical applications through research. Two sessions each will be held on nuclear-power equipment and welded structures. Other sessions will feature processes and procedures, cutting, pipe lines, design considerations, gas-shielded welding, brazing, stainless steel, titanium and zirconium, aluminum alloys, resistance welding, ultrasonic welding, heat effects on steel weldments, and weldability of steel and cast iron.

The three AIEE-sponsored sessions will cover arc-welding power supplies, welding-arc fundamentals and resistance welding. The subjects of the Ship Structure Committee's two sessions will deal with brittle fracture and welding in ship structures.

Twenty-one technical sessions, comprising 63 papers, will be presented from Monday through Friday at the Hotel Sherman.

Complete details of every activity on the convention agenda will be published in the April 1959 issue of the WELDING JOURNAL.

Welcome

•Sustaining Member

Titan Metal Manufacturing Co., Bellefonte, Pa.

This company has manufacturing plants located at Bellefonte, Pa., and Newark, Calif., with General Offices at Bellefonte, Pa. It is a leading producer of bronze brazing rods; brass, bronze and aluminum forgings, manufactured to blueprint requirements, for use in the welding and allied industries such as valve parts in the gas distribution industry; brass, bronze and aluminum machined parts; free-cutting brass, naval brass (leaded and nonleaded), manganese bronze—rods, bars and special shapes; brass pressure die castings; and brass wire.

M. J. Mianulli is the Sustaining Member representative.

•Supporting Companies

Effective Jan. 1, 1959:

Sylvania Electric Products Inc., Chemical & Metallurgical Division, Towanda, Pa.

Effective Feb. 1, 1959:

Allith-Prouty, Inc.
819 North Bowman Avenue
Danville, Ill.

Electric Steel Foundry
712 Porter Street
Danville, Ill.

Davis Awards for Papers on Design, Maintenance and Surfacing

To encourage the writing of papers on these subjects, the AMERICAN WELDING SOCIETY each year awards a silver medal with certificate for the best paper in each of these three fields: (1) Structural Design, (2) Machine Design and (3) Maintenance and Hard Surfacing. To be eligible for the award, a paper must be written by a single author, or by not more than two authors, and be published in the WELDING JOURNAL during the calendar year (for example, January through December 1959).

Authorship is not limited to AWS members. The papers are judged by a subgroup of the Committee on Awards of AWS. If no suitable paper has been published in the JOURNAL in any of the fields, no award is made for the year in question.

The awards are known as the A. F. Davis Silver Medal Awards. The medals are presented to the awardees at the Opening Session of the Annual Meeting. The medal for the best paper on maintenance and hard surfacing was established in 1958. The other two medals were established in 1957.

EMPLOYMENT OPPORTUNITY FOR ENGINEER

AWS is seeking an engineer to join Headquarters' Technical Staff as Assistant to the Technical Secretary.

Here are the duties—

Working with AWS technical committees in gathering and correlating technical data; preparing minutes, reports and other records of committee activities; editing standards for publication as completed.

Disseminating technical information in answer to inquiries from industry.

Related duties as assigned.

Here are the qualifications—

Ability to work with technical men at all levels in a cooperative manner. This is necessary to deal successfully with committee personnel, AWS members and the general public.

A degree in engineering, any branch.

At least three years experience in engineering work, preferably in welding or allied fields.

Here is an opportunity—

The man we are seeking has initiative and imagination and is interested in becoming familiar with welding in all its aspects and for every type of application. Salary will be commensurate with qualifications and experience.

If interested in being interviewed for this position, send a resume* of your education, experience and personal background to

Technical Secretary
American Welding Society
33 West 39th Street
New York 18, N. Y.

* Will be held confidential.

KEEPING YOU POSTED

by Fred L Plummer

● PRESIDENT HOGLUND visited headquarters on January 7th and 8th to confer on several SOCIETY projects including the new United Engineering Center which will be occupied by AWS together with other major engineering societies. An article devoted to this activity appeared in the February issue of the JOURNAL. Every AWS member is urged to join other engineers throughout the United States in supporting this cooperative project. Make your pledge through your Section representative or send it direct to AWS National Headquarters.

● DIRECTOR E. C. MILLER met with your Secretary on January 8th to discuss formation of a new AWS Section at Mobile. Mr. Miller planned to attend the activation dinner meeting announced for January 22nd by Chairman Leo D. Veal and Vice Chairman W. A. Pierre, Jr.

● THE FOLLOWING DAY Treasurer Rockefeller held a meeting of his Group Insurance Committee with Vice President Thomas, Director Alcock, staff members and an insurance management representative in attendance. This group will meet again in Pittsburgh on February 18th prior to a Board of Directors meeting to be held there the next day.

● STAFF MEMBERS also met with Convention Chairman Dato on January 9th to discuss possible speakers for the Annual Dinner to be held in Chicago, April 6th. The address will probably include predictions of future developments in missiles, rockets and space travel.

● FRANK DAVIS, director of the AEC welding group, visited headquarters this same day to discuss activities of the AWS-AEC liaison committee and also those of the International Institute of Welding.

● PAST PRESIDENT J. J. Chyle was in New York on January 12th and again during the week of January 19th. He is chairman of the AWS-AEC liason committee and active on many other SOCIETY committees.

● IIW PAST PRESIDENT Howard Biers reported to WRC Director Spraragen and your Secretary on January 14th concerning a meeting of the IIW Executive Council held in Paris last December. Dr. Biers is Chairman of the American Council of IIW for which your Secretary is now American Secretariat.

● EARLY ON THE MORNING of January 14th your Secretary joined President-elect C. I. MacGuffie for a trip to South Bend, Ind., via Cleveland, Toledo and Fort Wayne. J. F. Lincoln provided congenial company on the plane from Cleveland to Fort Wayne. Secretary W. G. Fassnacht and Chairman John Weis were waiting as the plane landed without our baggage and an hour late due to weather delays. Director Chouinard, who is also Vice President-elect, drove from Chicago for the dinner meeting of the Michiana Section at which Mr. MacGuffie presented an excellent discussion covering the economics of machine welding. Several associates of Mr. MacGuffie, including D. Spoor, also traveled from Chicago to attend this meeting.

● LEAVING SOUTH BEND at 6:55 the following morning, Mr. MacGuffie and your Secretary missed a 17-in. snowfall which closed airports and highways, and created a temporary state of emergency a few hours after our departure to Chicago, where we had a morning meeting with Chairman N. S. Strandwitz, and Director Chouinard and staff member Phillips concerning a possible welding industry exhibit at the Chicago Museum of Science and Industry.

● THAT AFTERNOON was devoted to a meeting of the Chicago Arrangements Committee for the Annual Meeting and Welding Exposition to be held there April 6-10. Exposition Manager Kenworthy reported contracts for more exhibit space than at any previous exposition. Convention Manager Mooney indicated that the housing committee was assigning rooms to fill the large number of requests mailed to the housing bureau. Chairman McPhee called for reports from committees planning the President's Reception, Annual Dinner, Ladies' Entertainment, Technical Sessions, Plant Tours (including a visit to the Dresden Nuclear Power Station), Publicity, Panel Discussions, Welded Products, Hospitality, Signs, Transportation and the many other features that make up our conventions. All committee reports were highly satisfactory.

● PRESIDENT-ELECT MacGuffie and staff members joined the Chicago Section at their dinner meeting at which Chairman Mueller called on Mr. MacGuffie and your Secretary for brief remarks before Omer Blodgett gave an outstanding talk on design for welding. Mr. Becker discussed educational programs of the Section and presented an engraved certificate of appreciation to Adam Bunk, accepting for President Michaels of the Chicago Bridge and Iron Works, for their fine cooperation in these programs.

● FORMER TREASURER Russ Donald, who is president of Electrarc, Inc. of Boston, visited your Secretary on January 19th and described processes he has developed for swedging and welding thin-gage aluminum tubes around coaxial cables with many types of coatings and insulating synthetics.

● THIS SAME DAY was distinguished by a long distance call from Director Jack York in Baton Rouge and a conference with Technical Activities Committee Chairman Art Kugler.

● JANUARY 20th brought snow and rain to Connecticut as your Secretary joined President Hoglund and his associate P. B. Dickerson for a trip to New London, a luncheon at Groton Motor Inn with officers of our Hartford Section, and an interesting inspection of welding and engineering facilities and activi-

APRIL IS NATIONAL WELDED PRODUCTS MONTH
VISIT THE A.W.S. WELDING SHOW

CHANGE OF RESIDENCE ADDRESS OR COMPANY AFFILIATION

DATE.....

NAME ..... (LAST / FIRST / MIDDLE)

RESIDENCE ADDRESS

..... (STREET)

..... (CITY / ZONE / STATE)

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..... (CITY / ZONE / STATE)

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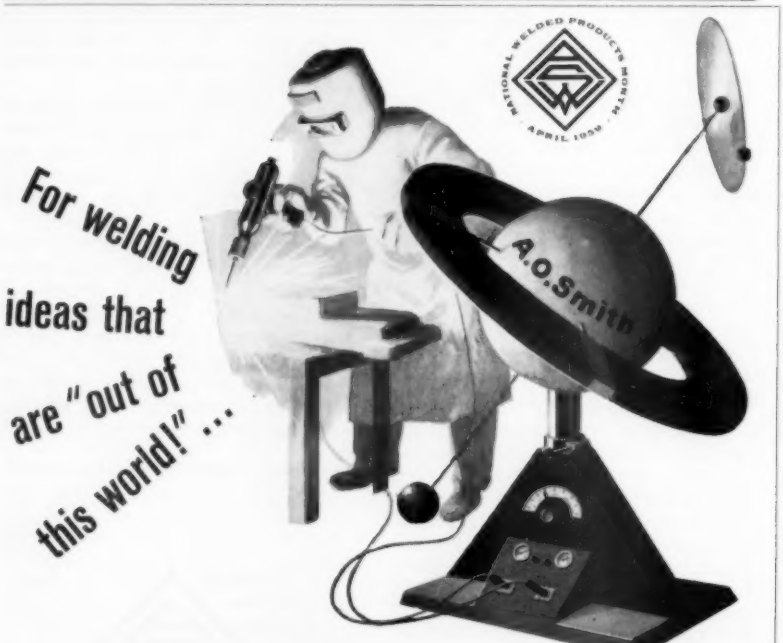
Mail should be sent to my residence ☐ company ☐ (check one)

I wish to be affiliated with the.....AWS Section

NOTE: To assure that your copy of the Welding Journal is mailed to your new address, this change of address notice must be received at American Welding Society, 33 West 39th Street, New York 18, N.Y., no later than the 25th of the month previous to issue mailing.



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ties of Electric Boat Division of General Dynamics. In spite of bad weather and difficult driving conditions, a large and enthusiastic group of AWS members met at the Villa Maria Restaurant near Hartford to listen to President Hoglund, your Secretary and Mr. Dickerson who presented the technical talk covering the performance of welds in some of the aluminum alloys. Chairman G. W. Kirkley (now Director-elect) and Vice Chairman W. A. Duncklee provided local transportation, acted as hosts and presided at the meeting. Following the meeting Clinton Swift drove your Secretary to New Haven for a very late return to Stamford by train.

● DURING THIS SAME DAY Publicity Committee Chairman Scherer and Information Director Phillips held a well-attended meeting of the Publicity Committee in your Secretary's office.

● DIVISIONS AND EXECUTIVE Committee of PVRC met in New York during the next two days with many AWS members in attendance.

● ON JANUARY 23RD at Fort Wayne, Ind., and again on January 26th at Rochester, N. Y., your Secretary joined President Niels Miller, of Miller Electric Co. in AWS Section meetings. Details will be reported next month.

● ON JANUARY 27TH your Tellers Committee canvassed nomination ballots for directors and national officers, and reported no "write in" nominations, thus assuring election of all of the official nominees presented in the December issue of the JOURNAL.

● THE MIDWEST Welding Conference, jointly sponsored by Armour Research Foundation and our Chicago Section, provided a fitting climax to January welding activities.

● TECHNICAL SECRETARY Fenton reports that the new *Soldering Manual* will be published in April and calls your attention to the report on corrosion protection of carbon steels which appears in this issue.

● DIRECTOR E. C. MILLER reports that W. S. Wells and others are actively working to reactivate the AWS Atlanta Section.

● WHEN YOU READ this page early in March, President Hoglund and your Secretary will be on an extended trip which will include visits with AWS Sections at Chattanooga, Nashville, Oak Ridge, Birmingham, Pascagoula, New Orleans, Baton Rouge, Dallas, Los Angeles and other west coast cities.

Fred L. Plummer

TECHNICAL PROGRESS

Automotive Welding Group Plans Session for National Fall Meeting

The General Motors Technical Center in Warren, Mich. was the site of another meeting of the AWS Automotive Welding Committee. This group is completing the first comprehensive welding manual for automotive designers. The Committee also expressed definite interest in sponsoring a session at the AWS Annual Meeting to be held in Detroit in the Fall of 1959. A tentative program for this session was outlined dealing with recent developments in automotive welding.

TAC Discusses New Committee

The Executive Subcommittee of TAC met in New York recently to consider a host of technical items including the approval of three new publications. In addition, one item of particular interest was the formation of a new committee on Welding Concrete Reinforcing Steel. The use of welding has increased rapidly in this field and is the subject of much controversy regarding correct welding procedures. It is expected that the new committee will have a Recommended Practice on this subject available by the end of this year.

Soldering Manual Completed

The *Soldering Manual*, the result of the AWS Committee on Brazing and Soldering, has been completed. Publication is scheduled for the first week in April to coincide with the AWS 40th Annual Meeting in Chicago.

Cooperation with Canada on Metallizing

The AWS Committee on Metallizing has forwarded two new standards to the Canadian Government Specifications Board for their comments. This is in accordance with an agreement made with the Canadians whereby neither group will issue any standard on metallizing without obtaining comments of the other.

Recently, the Canadians abandoned their old system of metallizing symbols in favor of the system devised by the AWS Committee. The designation of metallizing on drawings is now identical in the United States and Canada with industries in both countries deriving mutual benefit from this arrangement.

Welding of Cast Iron Investigated

The AWS-AFS Joint Committee on Welding Iron Castings has completed the second phase of their test program to find the best way currently known to weld cast iron. Fourteen companies are participating in welding test samples of gray, nodular and malleable cast iron by the arc, gas and braze welding processes.

In the first phase of the program, each of the participating companies welded a number of standard samples of cast iron (gray, nodular and malleable) by whatever procedures they thought best. All test samples were cast in one foundry to eliminate variables in the base metal. Arc, gas and braze welding as well as special welding techniques were tried by the various participants with a wide variety of filler metals. All samples were then forwarded to one laboratory where they were examined by nondestructive and destructive tests. One laboratory performed all the test work so that variations in testing equipment would not be a factor. The data obtained indicated that certain welding procedures appeared promising.

In the second phase, which has just been completed, each of the participating companies used the same welding procedure in an effort to see if the results obtained are reproducible. The next meeting of the committee, scheduled for March in Detroit, will review and evaluate the test data.

Gas Piping Systems Studied

New York was the site of the December meeting of the Oxy-Acetylene Committee of the International Acetylene Association. Part of the meeting was devoted to a discussion of the use of aluminum piping and tubing for oxygen and fuel gas piping systems for welding and cutting. A subcommittee was appointed to review the available information and report its findings at the next meeting on March 9th and 10th in New Orleans.

Water Tanks and Reservoirs

The American Water Works Association, together with AWS, issues the standard requirements for the design, fabrication and erection of elevated steel water tank, standpipe and reservoir structures. An Addenda to the 1955 edition of the Standard Specification has been prepared and will soon be available.

Welding Symbols Chart Well Received

Concurrent with the issuance of the new edition of the Standard Welding Symbols, a new idea was tried: a summary chart of welding symbols in an $8\frac{1}{2} \times 11$ in. size for desk use was introduced on an experimental basis. The reaction of industry to this idea was very gratifying. In the short space of three months, our initial supply of 5000 copies was exhausted; a second printing is now underway.

Corrosion Protection of Steel

This issue of the Journal contains a report on the corrosion protection of carbon steel by metallizing with zinc and aluminum. Prepared by the AWS Committee on Metallizing, this report contains the results of the first three years of exposure of more than 4000 specimens. The data indicate that the sprayed zinc and aluminum are affording complete protection to the base steel after the three-year exposure period. Aluminum, however, is superior to zinc in sea-water immersion. This report will undoubtedly arouse widespread interest. This is evidenced by the fact that advance orders have already been received for 20,000 copies.

SECTION NEWS AND EVENTS

As Reported to Catherine M. O'Leary

Connecticut

GAS CUTTING

Bridgeport. — The *Bridgeport* Section met at the Fairway Restaurant on January 15th for dinner and then adjourned to the Bullard Havens Technical School to hear a very interesting talk on "Gas Cutting," using both acetylene and propane. The talk was given by Joseph F. Kiernan of the Air Reduction Co., Union, N. J. Mr. Kiernan made comparisons between acetylene, propane and natural gas, emphasizing that each company must evaluate what is most economical for them to use.

District of Columbia

WELDING-ELECTRODE METALLURGY

Washington.—D. C. Smith, chief metallurgist, Electrode Division, Harnischfeger Corp., Milwaukee, Wis., was the guest speaker at the Nov. 20, 1958 meeting of the *Washington* Section held in the Perpetual Building Auditorium. Dinner at O'Donnell's Sea Grille preceded the meeting.

Dr. Smith's illustrated talk on "New Developments of Welding-Electrode Metallurgy" included a brief review of the history of electrode developments, and of improvements that have been introduced since World War II. The development of the low-hydrogen type electrode was the most significant improvement or development that took place at this time, according to Dr. Smith. The next step of significance was the introduction of iron powder into the electrode coating.

The improvement of impact transition-temperature curves, which is largely due to the introduction of iron powder and a better balance of alloys in the coatings, followed. With the introduction of iron powder into the low-hydrogen type of coverings, it was made possible to increase the carbon content of the weld, thus opening up an entirely new series of heat-treatable electrodes. Also, it was possible for the development of the ultra high-tensile weld metal.

SPEAKS ON ELECTRODES

D. C. Smith spoke on new developments of welding-electrode metallurgy at the November 20th meeting of Washington Section. Shown above are Section Chairman Mike Godfrey, left, and Dr. Smith

RESEARCH IN STEIL INDUSTRY

Washington.—A joint meeting of the AWS-ASM *Washington* Sections was held on Monday, Dec. 8, 1958 at the Dodge Hotel.

One of the guests of honor at the meeting was William S. Pellini, supervisor of Metallurgy Division of U. S. Naval Research Laboratory. President G. O. Hoglund presented to Mr. Pellini a certificate of appreciation in recognition of his outstanding contributions to the national educational program of the AWS.

Technical speaker was Oscar T. Marzke, vice president, Fundamental Research, United States Steel Corp. Dr. Marzke's subject, "Some Current Research in the Steel Industry," primarily concerned a study of factors that influence mechanical properties.

Dr. Marzke stated that with electron-microscope techniques, it was observed in studies of the transformation of austenite to pearlite that the carbide lamellae do not touch the austenite-ferrite interface (optical micrographs show no such gap). The existence of this gap has led to the development of a model for the transformation reaction. This model can account quantitatively for the effect of temperature and qualitatively for the influence of alloying elements on the austenite-pearlite transformation.

In view of the many discrepancies that exist in the literature on both the shape and composition of the carbide precipitates that are formed during the aging process in low-

WASHINGTON SECTION ADDRESSED BY MARZKE

Some of the current researches in the steel industry were discussed by Oscar T. Marzke at the December 8th meeting of Washington Section. Dr. Marzke is shown above delivering his talk

At same meeting, AWS President G. O. Hoglund presented Wm. S. Pellini with a certificate of appreciation for his contribution to the AWS national educational program

SECTION MEETING CALENDAR

APRIL 1

CLEVELAND Section. "Hard Surfacing."

APRIL 2

NORTHERN NEW YORK Section. Pittsfield Night. "Applications in Heavy Weldments," T. Walsh, Avery & Saul Co.

SAN ANTONIO Section. "Introduction to the Heat Treatment of Metals," B. D. Rowland, Earl M. Jorgensen Co.

APRIL 6

LEHIGH VALLEY Section. Walp's Restaurant, Allentown, Pa. Dinner 6:30. Meeting 8:00. Plant Visit.

APRIL 8

STARK CENTRAL Section. "Low-Hydrogen Electrodes," Donald Helton, Harnischfeger Corp.

APRIL 9

IOWA-ILLINOIS Section. "Inert-Gas Welding," G. K. Willecke, Miller Electric Mfg. Co.

KANSAS CITY Section. World War II Memorial Bldg., Paseo Ballroom, Kansas City, Mo. Social Hour 5:30. Dinner 6:30. "Welding—Its Application to Rockets," F. M. Stevenson, Aerojet General Corp.

MADISON Section. Eagles Club, Madison, Wis. "Maintenance Welding Problems." Panel Discussion.

NASHVILLE Section. "New Processes."

SAGINAW VALLEY Section. "Gas Welding."

APRIL 10

NORTH CENTRAL OHIO Section. Joint Meeting with Columbus Section at Marion, Ohio.

APRIL 13

NORTHWEST Section. Minneapolis, Minn. "Special Problems in Welding Aluminum," Howard Adkins.

APRIL 14

DAYTON Section. Kuntz's Cafe, Dayton, Ohio. Social 6:30. Dinner 7:00. Meeting 8:00. "Sheet-Metal Fabrication of Automobile Components," J. F. Cantalin, Fisher Body Central Office.

NEW YORK Section. Victor's Restaurant, New York City. "Gas-Shielded Metal-Arc and Tungsten-Arc Welding," Ed Dato, Linde Co.

NORTH TEXAS Section. Technical session and dinner, 6:30 P.M., at Western Hills Inn.

NORTHWESTERN PENNSYLVANIA Section. Erie, Pa. Battle of the Sections.

PITTSBURGH (Johnstown Meeting). V.F.W. Post #155, Johnstown, Pa. "Inert-Gas Welding," L. W. Kunkler, Air Reduction Sales Co., and R. E. Lawther, Westinghouse Electric Corp.

WESTERN MASSACHUSETTS Section. Trase's Restaurant, Springfield, Mass. 6:30. Coffee Films: The Pulse of Time and The Monza Challenge. "Automatic Brazing Machinery," Charles A. McFadden, Selas Corp. of America.

APRIL 15

PASCAGOULA Section. Cotita's Restaurant, Pascagoula, Miss.

APRIL 16

BATON ROUGE Section. Baton Rouge, La. Election of Officers.

IOWA Section. Des Moines, Iowa. "Solving Difficult Welding Problems," R. Gorman, Eutectic Welding Alloys Corp.

LOS ANGELES Section. Joint Meeting with ASM. Rodger Young Auditorium.

NASHVILLE Section. Chamber of Commerce Building. 8:00. "Fabrication Techniques at A. O. Smith," A. E. Johnson.

APRIL 17

FOX VALLEY Section. Appleton Elks Club, Appleton, Wis. 7:45. "Pipe Welding and Pressure-Vessel Welding."

MARYLAND Section. Engineers Club, Baltimore, Md. Battle of the Sections. Lehigh Valley, York and Maryland Sections participating.

MILWAUKEE Section. Milwaukee, Wis. Ambassador Hotel, "General Principles of Nondestructive Testing," Al Kota, A. O. Smith Corp.

WESTERN MICHIGAN Section. Grand Rapids, Mich. Annual Symposium.

APRIL 20

PHILADELPHIA Section. Engineers Club, Philadelphia, Pa. Battle of the Sections. York, Lehigh Valley, Susquehanna Valley and Maryland Sections.

APRIL 21

HOLSTON VALLEY Section. Johnson City, Tenn. "Induction Heating and Stress Relieving of Welded Joints," Gerald Scott, Hobart Bros.

NEW JERSEY Section. Essex House, Newark, N. J. Dinner 6:30. Meeting 8:00. Roy B. McCauley, Ohio State University.

OLEAN-BRADFORD Section. Hotel Fassett, Wellsville, N. Y. Dinner 7:00. Meeting 8:30. "Welding Stainless Steel," Wayne Wilcox, Arcos Corp.

NEW ORLEANS Section. New Orleans, La. Annual Election of Officers.

TOLEDO Section. Toledo, Ohio. Annual Clinic—Welding Metallurgy.

YORK-CENTRAL PENNSYLVANIA Section. York, Pa. Battle of the Sections.

APRIL 22

LOUISVILLE Section. Louisville, Ky. "60-cycle to 180-cycle and Higher Frequencies for Induction Heating."

APRIL 23

NIAGARA FRONTIER Section. Cypress Inn, Buffalo, N. Y. Dinner 6:45. Meeting 8:15. "Welding of Nickel and High-Nickel Alloys," R. P. Culbertson, Haynes Stellite Co.

APRIL 24

INDIANA Section. Plant Trip—Bell Telephone Laboratories and Western Electric Plant, Indianapolis.

APRIL 27

SAN FRANCISCO Section. "Hard Surfacing by Welding," Richard K. Lee, Alloy Rods Co.

Editor's Note: Notices for June 1959 meetings must reach JOURNAL office prior to March 20 so that they may be published in May Calendar. Give full information concerning time, place, topic and speaker for each meeting.

carbon steels, extensive electron microscope studies with the electron replica technique have been carried out. It has been found that the carbides formed in specimens quenched to room temperature and then aged at a higher temperature have a complex dendritic appearance. When aged at low temperatures, the dendrites are fine and lacy, while when aged at higher temperatures they become more compact and massive. On specimens quenched directly to the aging temperature, both dendritic and oblong plate-like structures are found. In all cases, electron diffraction data show the carbides to be cementite.

An electron micrograph having a magnification of $\times 500{,}000$ was shown to illustrate the form that titanium carbide takes on precipitation from stainless steel. These carbides are thin, rectangular plates and are stacked like playing cards that have been fanned out. Several electron micrographs were also shown to illustrate the appearance of dislocations in stainless steel.

Evidence was given to show that hydrogen and nitrogen reach an "equilibrium value." This value varies with the extent of cold work—the more the cold work, the higher the value. The increase in this value has been found to be directly proportional to the increase in the atom vacancies caused by the generation of dislocations during the cold working. This suggests the formation of a hydrogen or nitrogen dislocation compound analogous to that of a chemical compound.

Finally, some preliminary information was given to show the improvement in physical properties that may be possible through application of some of the basic concepts on formation and locking of dislocations. Under one set of test conditions, stainless steel that had been processed by a combination of cold working and precipitation gave a rupture life approximately ten times greater than that of untreated material. Its minimum creep rate was also lowered almost a hundredfold. The preliminary nature of these results was emphasized, and the necessity for more work to determine if such results can be consistently obtained without any detrimental effects was pointed out.

Louisiana

METALLIZING

Baton Rouge.—The regular meeting of the *Baton Rouge* Section

was held at the Log Cabin Restaurant on Dec. 18, 1958.

After a very good barbecued chicken dinner, 35 members and their guests heard Emil J. Dalbo of Metallizing Engineering Co. of New Orleans present a talk on "Metallizing." Mr. Dalbo's talk was accompanied by a sound movie and put special emphasis on new equipment and new types of coatings, both metals and ceramics. This was the first time a program of metallizing was presented to the Baton Rouge Section and Mr. Dalbo's talk was followed by a lengthy question and answer period.

Maryland

CLAD STEELS

Baltimore.—"Manufacture, Fabrication and Application of Lukens-Clad Steels," was the subject of a talk given by Louis K. Keay, manager, Technical Service for Lukens Steel Co., Coatesville, Pa., at the January 16th meeting of the *Maryland* Section held at the Engineers Club.

Mr. Keay gave a very interesting talk on the general subject of clad steels and the various methods which have been in use. He then gave, in particular, the process used at Lukens.

The Lukens method is the assembly of a piece of steel whose top and mating surface have been cleaned, then a piece of clad metal not quite so large in area whose mating surface has been nickel plated, are placed together. The opposite surface of the clad material is painted with a parting material. On top of these two plates a second clad plate is placed with its side painted with parting material placed against the parting material of the first clad plate.

Border strips are then placed on the first steel plate and around the two clad plates. The second clad plate has its nickel plated surface up and a second steel plate is then placed, with its cleaned side down, upon the plated surface of the second clad plate. This sandwich is welded together around the edges and is now ready for its first step in manufacture. This sandwich may be made up of various materials as it is a custom process and is made to customer's order.

The sandwich is carefully brought to the proper temperature for rolling and welding. It is then run through the rolling mills which reduce the section and increase the area of the sandwich and also weld together the steel backup with the clad surfacing material. A hole is placed in the backup steel to allow any air or gases between the two surfaces to be welded to escape.

The resulting sandwich is cut apart at the weld and separated by means of the parting material and the finished surface is now for the first time exposed, having throughout the process been protected by the backup steel.

The temperature to which the sandwich was subjected was a very critical part of the process. Heat treating after joining of metals is often a part of the process.

Mr. Keay spoke of the particular use to which the nickel plating upon the matching surface of the clad material was put.

The speaker showed a number of slides of various methods of welding clad metals and also how clad material can be oxygen cut.

The slides throughout the lecture and Mr. Keay's presentation gave a very comprehensive picture of the subject.

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Massachusetts

FUTURE OF WELDING

Boston.—James F. Lincoln, Chairman of the Board of the Lincoln Electric Co., Cleveland, Ohio, was the featured speaker at the *Boston* Section meeting held on Monday, December 8th, at the Bostonian Hotel. Mr. Lincoln spoke at length on the future of welding and today's trends in welding. With half a century of personal experience to draw upon, he made comparisons between the various joining methods in use over the years and showed how technological advances had outmoded many of them in favor of welding. He made an appeal for realistic codes and standards. "Let us not hamper our own industry," he said, "by making our welding codes and standards unduly restrictive. Instead, let us liberalize and simplify, wherever possible, within the standards of good engineering practice." Coffee speaker was National Secretary Fred L. Plummer, who spoke on SOCIETY affairs. He indicated how the work of the technical committees aided industry and pointed out that the best engineers in the country get together under the auspices of the

HERRSCHAFT DISCUSSES BRAZING

The topic of Donald C. Herrschaft's talk at the January 5th meeting of Worcester Section was "Brazing Challenges the Thermal Barrier." Mr. Herrschaft is shown, center, at speaker's table

AWS to draft codes, prepare manuals and write specifications. He mentioned the Society's part in welding education, the new Information Center established at headquarters and the AWS WELDING HANDBOOK, widely considered the "Bible" of the industry. He explained how membership in professional societies is encouraged by industry and leads to growth, recognition and promotion.

ULTRASONIC WELDING

Springfield.—The January 13th meeting of the *Western Massachusetts* Section was held at the Lido Restaurant.

Following an excellent dinner, a film entitled "Viva Mexico" was shown.

W. C. Potthoff, vice president of Aeroprojects, Inc., then gave an informative talk on "Ultrasonic Welding." He brought out that the company's subsidiary, Sonobond Corp., maintains welders ranging from a small 100-w size to 4000-w size, and progress is being made continually in the thickness of metals that can be welded.

A question-and-answer session was held at the end of Mr. Potthoff's talk. The response given to this part of the program showed a high degree of interest on the part of the members to this relatively new field of welding.

BRAZING

Worcester.—On Monday, January 5th, in below-zero temperatures, Donald C. Herrschaft, welding engineer at Handy and Harman, New York City, very generously came to *Worcester* to give this Section a very informative talk on "Brazing Challenges the Thermal Barrier." With the aid of slides, he discussed the gold-base brazing alloys and their uses, especially in jet engines. He pointed out that this type of high-temperature brazing by the platinum group of metals is in its infancy as compared to silver brazing 25 years ago.

The caliber of Mr. Herrschaft's talk was evidenced by a question period of one hour and forty-five minutes, a session agreed by all to have been very well spent.

Missouri

CO_2 WELDING

Kansas City.—One of the most successful meetings held by the *Kansas City* Section took place on January 8th at the World War II Memorial Building. The success of this meeting was due to a talk given by R. W. Tuthill, assistant manager of the Equipment Engineering Department, Air Reduction Sales Co., Union, N. J. Mr. Tuthill's talk was excellent in presentation and covered various methods and applications involving the CO_2-shielded metal-arc welding process. It was of particular interest to the welding engineer, welding operator, production personnel and executives. His talk was blended in with motion pictures and slides.

NEW JERSEY SPEAKER

Kenneth M. Spicer talked on the welding of dissimilar metals at the December 16th meeting of New Jersey Section

New Jersey

WELDING DISSIMILAR METALS

Newark.—Seventy members of the *New Jersey* Section met at the Essex House on Dec. 16, 1958 to hear more about the "Welding of Dissimilar Metals." Kenneth M. Spicer, assistant supervisor in the Mechanical Engineering Section, D & R Division of the International Nickel Co., explained that our nu clear age has brought with it an increasing requirement for the welding of many different metals to form a final structure that possesses special characteristics.

While there are numerous problems to be encountered in the welding of dissimilar metals, he pointed out, dilution and compatibility are of outstanding concern. The type of filler metal is governed by the nature of the welding process and the extent to which dilution can take place. He explained that some metals are compatible, and others are not. The extent to which a mixture can be formed during attempted welding is directly related to the compatibility.

Mr. Spicer also explained that it has been necessary to develop many types of electrodes to take care adequately of the many combinations of metals and welding processes and this extended experience has made it possible to predict weld results before a job is started.

Earlier in the evening, the members met at dinner for their customary exchange of greetings and then were shown a film, "Welding for Quality," through the courtesy of the Carpenter Steel Co. The meeting ended with a social get-together period with refreshments.

New York

TESTING MODERN AIRCRAFT

Hicksville, L. I.—On Dec. 4, 1958 the regular meeting of the *Long Island* Section was held at Henningsen's Restaurant in Hicksville.

LONG ISLAND SECTION HEARS ATTRIDGE

Thomas Attridge, shown receiving speaker's gift, spoke on testing of modern aircraft at the December 4th meeting of Long Island Section. Left to right, are A. Strickland, Mr. Attridge, R. E. Noble, C. Henne, and K. W. Berry

The meeting program opened with a talk by Thomas Attridge, a production and experimental test pilot for the Grumman Aircraft Engineering Corp. Mr. Attridge has an unusual claim to fame when some years back he shot himself down while piloting an F-105 jet fighter which ran into the path of its own bullets. With the aid of an action film of the Navy Blue Angels, he brought to life many of his exciting experiences.

WELDING OF ALUMINUM

Hicksville, L. I.—The *Long Island* Section had Paul Dickerson as guest speaker at its Nov. 13, 1958 meeting held at Henningsen's Restaurant. Mr. Dickerson, who is a member of the Joining Section of the Aluminum Company of America, New Kensington, Pa., has specialized in inert-gas arc-welding processes, arc cutting, pressure welding, ultrasonic welding, and the development of aluminum rods and electrodes. His talk dealt with the performance of arc welds in aluminum alloys.

WELDING MANGANESE STEEL

Hicksville.—On Jan. 8, 1959 the *Long Island* Section held its monthly meeting at Henningsen's Restaurant. Immediately following dinner, the principal speaker, Harry F. Reid, Jr. of the Technical Service Division, The McKay Co., York, Pa., was introduced and gave a very fine talk on the welding of manganese steel. Mr. Reid explained with clarity the many advantages of welding manganese steel with suitable electrodes.

GIVES COURSE IN WELDING METALLURGY

Bob Platz conducting class in welding metallurgy at recent lecture series sponsored by the Long Island Section

WELDING METALLURGY COURSE

Farmingdale, L.I.—Twenty-two persons completed an informative six-week course in "Welding Metallurgy," sponsored by the *Long Island* Section at the Long Island Agricultural and Technical Institute. The course covered the areas of basic metallurgy for background, then went into the metallurgical effects of metal joining on high-temperature steels, stainless steels, aluminum, titanium and magnesium alloys.

Thanks are due to three of the members who devoted much time and energy to presenting this course. They are Robert Witt of Republic Aviation, Robert Platz of Fairchild Engine Division, and Sal Messina of Grumman Aircraft Eng. Corp.

Due to the success of the fall lecture series, it is planned to offer another welding course in the spring.

WELD FAILURE

Albany.—What are the consequences of a weld failure? Depending on the circumstances, a weld failure may vary anywhere from having only a relatively minor effect to being catastrophic. But no weld failure goes completely unnoticed. Realization of this fact and the understanding that it is highly important to avoid weld failures prompted sixty members and guests of the *Northern New York* Section to attend the Jan. 8, 1959 meeting held at the Hot Shoppes Restaurant in Albany, N. Y. Those in attendance were well rewarded by the excellent talk which Helmut Thielsch, metallurgical engineer for Grinell Co., presented on "Why Welds Fail."

Although there are numerous codes and specifications whose purpose it is to regulate and control welding materials and fabrication procedures, weld failures nevertheless occur. Mr. Thielsch pointed out that part of the reason for these failures lies in two fallacies of the codes and specifications. The first fallacy is that it is frequently presumed that large welded structures will behave in the same manner as the small specimens which are tested to demonstrate that materials and procedures conform to the applicable specifications. Secondly, even though specifications require certain forms of inspection to be applied to all pressure vessel and many other welds, there are shortcomings in the inspection methods and specifications so that, even though dangerous defects may be present, they may go undetected.

Lincoln

WELDYNAMICS

NEWS ABOUT ARC WELDING AT WORK CUTTING COSTS

AEROGLIDE TRIMS WELDING COSTS 1/3 ...IMPROVES PRODUCT QUALITY

Structural parts are welded faster and easier with Jetweld.

Like many other manufacturers, Aeroglide Corporation of Raleigh, North Carolina, found themselves caught in a price-cost squeeze last year.

Aeroglide is one of the largest manufacturers of produce handling equipment and grain driers. All the equipment they build is welded and much of the welding is on sheet metal. Their biggest cost problem involved the sheet metal welds. Burn-through and spatter were eating up shop time and profits.

John Wyatt, Aeroglide's Shop Superintendent, "Our whole shop is more efficient because of improved welding methods."

John P. Wyatt, Jr., Aeroglide's shop superintendent and James F. Kelly, President, decided to seek outside help. They invited Kirk Sterling, a welding engineer with Lincoln's Charlotte, N.C. office to help them make a survey of Aeroglide's welding operations.

Working closely with Mr. Wyatt, Sterling made a careful analysis of their welding jobs. The burn-through and cleaning problems were solved with a switch to Fleetweld 37 electrodes which are specially designed for sheet metal welds. Greater production efficiency on heavier structural members was achieved with iron-powder Jetweld electrodes.

Mr. Sterling also conducted a five-day welding clinic which was voluntarily attended by Aeroglide's weldors and shop supervisors. Higher shop efficiency resulted from a better understanding of welding procedures as a result of the clinic.

The total effect—a 33% cut in welding costs.

Jim Kelly, Aeroglide's youthful president, commented, "The Lincoln people have done us a great service. Big industries can go to their suppliers and demand the products they need. Companies like ours depend on our suppliers to show us how to get the most out of what's available. Lincoln has helped us build a better product . . . and made a stronger Lincoln customer.

Aeroglide grain dryers, easier to assemble, sturdier and more efficient with welded construction.

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Contributing to and in conjunction with these basic fallacies, Mr. Thielsch cited five fundamental causes of weld failures. The first of these is improper engineering design in which sufficient flexibility in the over-all structure is not provided or in which the weld joint itself is improperly designed. Secondly, incorrect selection and specification of materials may lead to service or fabrication failures. Several striking examples were reported in which failures occurred in carbon-depleted zones of carbon steel or low-alloy welds adjacent to more highly alloyed base materials. These failures could have been avoided by proper selection of materials. Many failures have resulted from the third cause, defects in the base metal or weld deposit caused by faulty steel-making practice, careless steel forming, shaping or heat treating, defective electrodes, etc. All of these factors were thus introduced by the producer of the materials that were used. A fourth cause of weld failures is defective welding. Mr. Thielsch pointed out, however, that failures from this source are by far in the minority and that about three quarters of all failures in welded components result from one of the factors other than welding itself. Finally, failures in welded structures have occurred where service conditions were more severe than had been anticipated and, hence, more severe than the structure was designed to withstand.

Mr. Thielsch's excellent talk was further enhanced by numerous slides of failures in welded structures, the slides serving to illustrate the various causes of the failures.

Before the technical session and following a turkey dinner, a high-speed motion picture supplied by Air Reduction Co. was shown. It showed characteristics of the welding arc during inert-gas-shielded metal-arc welding with a consumable electrode.

NORTHERN NEW YORK SECTION HEARS THIELSCH

Helmut Thielsch gave a talk on "Why Welds Fail" at the January 8th meeting of the Northern New York Section. Shown above are, left to right, Ivar Johnson, Mr. Thielsch, John Cuturilo and Dick Nowell

Ohio

RESISTANCE WELDING

Cleveland.—The Dec. 10, 1958 meeting of the *Cleveland* Section held at the Scientific and Engineering Center, followed the regular pattern of social hour, dinner and technical meeting. The technical meeting was devoted to various aspects of resistance welding.

The principal speaker, James Dawson, welding engineer in the Fabrication Laboratory at the Redstone Arsenal, discussed the general process of resistance welding, and why it is used. Following his comments, four technical experts representing the four major resistance-welding manufacturers provided condensed technical talks of particular types of applications. F. A. Bodenheim, Federal Machine and Welder, covered the welding of medium to heavy sections, $^1/_8$ in. and up, outlining applications in structural, mobile equipment, etc. Welding of light sections from 20 gage to $^1/_8$ in. in the automotive and appliance industries was covered by W. A. Haessly, Taylor-Winfield. A. Schueler, Precision Welder Co., talked about high volume applications in commercial nonferrous materials such as welding radio tubes, transistors, etc. W. Rudin, Sciaky Bros., covered resistance welding in the missile field.

WELDING EDUCATION

Columbus.—The Jan. 9, 1959 meeting of the *Columbus* Section was held at the Student Union Building on the campus of the Ohio State University. The topic was "Welding Engineering at The Ohio State University." The meeting was a panel presentation by three members of the Educational Activi-

RESISTANCE WELDING IS THEIR SUBJECT

Dave Adair was moderator at December 10th meeting of Cleveland Section

James Dawson was principal speaker on resistance welding

F. A. Bodenheim covered welding of medium to heavy sections

Welding of light sections was described by W. A. Haessly

A. Schueler talked about high-volume applications

Brief summary of educational series was given by Wasil Romance

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ties Committee of the AMERICAN WELDING SOCIETY. The first speaker was Howard B. Cary, Director of the Hobart Brothers Technical School, Troy, Ohio. Mr. Cary's subject was "Welder Apprentice and Welding Technician Training." Mr. Cary divided the welding field into three categories, the welder, the welding technician and the welding engineer. The qualifications, training and duties of the men in each category were described. He pointed out that the rapid growth in the welding industry has broadened the communication gap between the welding engineer and the welder. For this reason more technicians are being employed in the welding field.

The second speaker was Professor Roy B. McCauley, chairman of the department of Welding Engineering of the Ohio State University. Professor McCauley's subject was "Welding Engineering on the College Level." Professor McCauley discussed the courses which a high-school student should take to prepare himself for engineering. He then discussed the welding engineering curriculum at Ohio State University which has recently been accredited by the Engineering Council for Professional Development. The Ohio State University is one of three universities in the country which offers a degree in Welding Engineering.

The third speaker was W. G. Leaman, welding engineer at North American Aviation, Columbus, Ohio. Mr. Leaman's subject was "Job Opportunities and Requirements." He discussed the various job opportunities for welders, welding technicians and welding engineers, giving the salary ranges in each category for various industries.

Seventy-one people attended this meeting, including thirty-seven high-school students. One student traveled a distance of one hundred miles to attend the meeting.

It was the opinion of those present that to obtain the personnel needed in the welding industry high-school students must be interested in welding. A meeting such as this brings welding to the attention of high-school students, some of whom will be needed to fill the vacancies in our ever expanding industry.

ALUMINUM WELDS

Dayton.—The Jan. 13, 1959 meeting of the *Dayton* Section was held at the Engineers Club with 40 members and guests attending.

An interesting color film on welding, brazing and soldering of aluminum opened the meeting.

F. R. Collins, head of Joining Section, Process Metallurgical Division, Aluminum Company of America, was the guest speaker. His topic, "Porosity in Aluminum-Alloy Welds," illustrated with slides, covered a method of grading porosity and the technique used to correct the condition.

SPEAKS ON WELD POROSITY

The topic for F. R. Collins' talk before the Dayton Section on January 13th was "Porosity in Aluminum-Alloy Welds." Here Mr. Collins, left, receives a souvenir of the occasion

PLANT TOUR

Barberton.—On the evening of Nov. 18, 1958, 118 members and guests of the *Stark Central* Section journeyed to the Barberton plant of the Babcock and Wilcox Co., well-known manufacturers of steam generating equipment. There they were met by George G. Brown and a number of his able assistants. They were guided in small groups throughout the works following a predesignated mapped path. The guides were well informed on the technical phases of the projects in process, as well as the technical and mechanical problems involved in each.

Actually, on this two-hour tour, only the highlights of this tremendous plant could be seen, but these left the visitors marveling at its many facets and yet, despite the scale of this huge plant, control of quality and adequate supervision were obvious. Material procurement and testing, handling, layout and setups, foundries, preheatings, quality controls, welding processes and techniques; all these were observed in the one short evening and followed by the enjoyable coffee and donuts served in the cafeteria.

OXYGEN CUTTING

Canton.—The Dec. 10, 1958 meeting of the *Stark Central* Section was held at the Towne and Country Restaurant, Perry Heights.

The speaker, Ed S. Young, sales manager for the Northeastern Ohio district of the Harris Calorific Co., discussed, described and anecdoted his subject of natural gas oxygen-cutting operations. He impressed upon the audience the necessity of modern equipment and techniques to obtain extreme economy and all benefits possible from the use of natural gas.

Tennessee

PLANT TOUR

Nashville.—On January 8th, a tour was made of the Ford Motor Co.'s Nashville Glass Plant by 48 members and guests of the *Nashville* Section. The tour followed all of the operations involved in the manufacture of laminated flat and curved automotive glass from raw materials to finished product.

Texas

FLUX-CORED ELECTRODES

Dallas.—The *North Texas* Section met for dinner and a meeting on Tuesday, January 13th, at the Western Hills Inn. Sixty-one members and guests were present.

The guest speaker was J. A. Howery, supervisor, Technical Service Department for National Cylinder Gas Co., St. Louis. Mr. Howery's subject, "A New CO_2 Welding Process," covered the development of the flux-cored electrodes for use with carbon-dioxide shielding and their application to the welding of mild steel. A series of slides accompanying Mr. Howery's presentation illustrated several production applications of the CO_2-shielded flux-cored electrode process, and showed the time and cost savings possible with this process. One of the highlights of the session was a color film, made by a special high-speed photographic process, comparing the arc characteristics of E6012, E6024, E6027 and the flux-cored electrodes.

INSTALLATION OF OFFICERS

San Antonio.—The January meeting of the *San Antonio* Section was held on January 5th at Youngblood's and forty-five members enjoyed a fried chicken dinner.

The guest speaker, Monroe E. Smith of the Texas Highway De-

partment, was hospitalized with pneumonia and unable to attend.

An impressive installation service for the new officers and directors was held at the regular meeting time.

The following were installed:

Chairman—W. B. Hamilton, Jr.
1st Vice Chairman—Fred W. Smith
2nd Vice Chairman—C. E. Hosier
Secretary—John E. Bergeron
Treasurer—E. E. Wagner
Directors—1959-60: Charles R. Brownrigg, Josh Ewing, Jr., Reno J. Billimek, Wm. A. Ferrari and Richard Rodreguez, Sr.

Wisconsin

POWER SOURCES

Beloit.—A regular meeting of the *Madison* Section was held January 15th, at the Elks Club in Beloit, Wis.

Dinner was served at 6:45 P.M., immediately followed by a film depicting life in Japan.

Guest speaker for the evening was G. K. Willecke of the Miller Electric Co., Appleton, Wis., who made a fine presentation of the subject "An Evaluation of Various Types of Power Sources for Welding." Included in the talk was a brief history of power sources, volt-amp curves, duty cycle ratings, CP and balanced wave machines, and other pertinent topics. Following the presentation, Art Gast and Roy Stroessenreuther, also of Miller Electric, assisted in answering questions of the 50 members in attendance.

SUBMERGED-ARC WELDING

Milwaukee.—The *Milwaukee* Section held their monthly meeting on Friday, January 16th, at the Ambassador Hotel.

Lew Morrison, Hunting and Fishing Editor of the Milwaukee Sentinel, was the after-dinner speaker. His talk was on outdoor life in Wisconsin. He was national fly-casting champion and gave a very good demonstration on fly casting and bait casting, which was enjoyed by all.

The technical speaker was George Motzenbecker, Chicago district manager of Electric Welding Sales for Linde Co. His topic was "Submerged-Arc Welding." He told of the advances that have been made in wire and flux compositions, the use of multi-electrodes and machinery.

Both of the above talks were enjoyed by 139 members.

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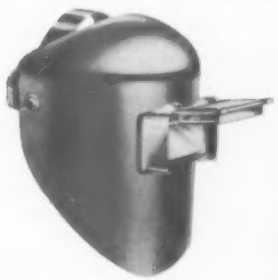

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All helmets have Ratchet Adjustment *"free floating"* Headgear, impact resistant adjustable friction joints and adjustable chin rest. Glassholders are available in plastic, steel or Dowmetal, in either fixed-front or lift-front styles.

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MEMBERSHIP CLASSIFICATION

A—Sustaining Member
B—Member
C—Associate Member
D—Student Member
E—Honorary Member
F—Life Member

TOTAL NATIONAL MEMBERSHIP

Sustaining Members	198
Members	5,994
Associate Members	5,679
Students	222
Honorary Members	9
Life Members	16
Total	12,118

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BOSTON

Novak, Allen A. (D)

BRIDGEPORT

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CANADA

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CAROLINA

Benjamin, John R. (C)
Campbell, Frederick C. (C)
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CHICAGO

Evers, Neal (C)
Francis, John G. (B)
Hilk, Harry G. (B)
Korbilas, Christ P. (B)
Matthews, John R. (C)
Weber, Wilmer W. (C)

CLEVELAND

Henry, John A. (C)
Prater, James C. (C)
Rogers, Frank (C)

COLUMBUS

Baker, Jack (D)
Rebert, Gerald C. (C)
Twohey, J. A. (C)

DAYTON

Fast, Ronald D. (C)

DETROIT

Henderson, Andrew B. (B)
King, Robert J. (C)
McNear, Richard N. (B)
Meltvedt, Arthur M. (D)
Scofield, John H. (C)
Straith, William M. (C)

HARTFORD

Lister, F. M. (C)
Mougenot, Marcel O. (B)

HOLSTON VALLEY

Faust, Jake (C)
McClanahan, G. K. (C)
Seneker, John A. (C)

HOUSTON

Bell, K. L. (C)
Civilla, Joseph R. (C)
Durbin, Harvey J. (C)
Hicks, Malvin K. (C)
Holmas, John D. (C)
Hurst, John E. (B)
McGrew, Wallace, R. (B)
Powell, J. Edwin (C)
Quantic, Myron W. (B)
Sanders, Floyd C. (C)
Sullins, Roy Wayne (D)
Swonke, James D. (C)
Underwood, Adelbert C. (B)
Wood, John Donald (B)

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Stringer, Charles (C)

IOWA-ILLINOIS

Rettig, Charles H., Jr. (C)

KANSAS CITY

Hansen, Carl U. (C)

LONG ISLAND

Cavanaugh, Robert (C)
Miele, Louis A. (C)
Preusse, Carl (C)
Schwartz, Milton (C)
Shannon, Robert J. (C)
Supper, Walter (C)

LOS ANGELES

Arakelian, William R. (B)
Childers, Harold F. (B)
Martin, Nathan L. (B)
Ross, Oran Lee (B)

MADISON

Schultz, Merlin E. (B)

MAHONING VALLEY

Leonhart, Donald F. (C)

MICHIANA

Anderson, Arthur E. (C)

MILWAUKEE

Goodney, John W. (B)

NASHVILLE

Dyehouse, James F., Sr. (C)

NEBRASKA

Malm, Raymond R. (B)

NEW JERSEY

Bleiweis, Alfred (C)
Mackiewicz, Wally (C)
Scherer, William A. (C)

NEW YORK

Anselmine, Ludwig (B)
Gribbin, John B. (B)
Gross, William J. (B)
Kohlmann, Gunter (B)
Livingston, J. P. (B)
Minasy, Arthur J. (B)
Rothstein, Samuel (B)

NIAGARA FRONTIER

Burgie, John H. (B)
Harte, John J. (B)

NORTH CENTRAL OHIO

Neuman, Rene B. (C)

NORTH TEXAS

Blaesing, Raymond A. (B)
Sampson, H. E. (B)

NORTHEAST TENNESSEE

Dane, Bruce E. (C)

NORTHWESTERN PA.

Boyer, Dennis C. (C)

PASCAGOULA

Caldwell, Walter W. (C)
Mancill, Gerald W. (B)
Phillips, Hilary Hugo (C)

PHILADELPHIA

Addison, Harry J., Jr. (B)
Cahan, Barton M. (B)
Harrer, Edward C., Jr. (B)
Keane, Robert A. (C)
Poth, John P. (B)

PITTSBURGH

Brehl, Carl A. (B)
Buyan, Nicholas J. (B)
Curtis, Vincent V. (C)
Elder, Joseph A. (C)
Flick, James W., Jr. (C)
Fortune, J. Arthur (B)
Harvard, Jack (B)
Kuenzi, Walter (B)
Kochanowski, John L. (C)
Krosky, Joseph J. (C)
Lytle, Martin H. (B)
Mooney, Carl C. (B)
More, Clarence L. (B)
Wycoff, Virgil G. (C)

PORTLAND

Reeder, Roy (B)
Van Buskirk, Roderick Wm. (D)

PROVIDENCE

Ellis, Donald E. (B)
Wagoner, Frederick Charles (C)

RICHMOND

Marsh, William H. (C)

ROCHESTER

Dickinson, William D. (D)
Beebee, Alexander M. (B)
Roethel, Gerald F. (D)

SAGINAW VALLEY

Montgomery, Wilson D. (C)

ST. LOUIS

Burkhart, Walter E. (C)
Toenjes, Louis A. (C)

SAN ANTONIO

Mackie, Charles (D)
Schmidt, Tex (D)

SAN FRANCISCO

Brooks, Phillip T. (C)
Erickson, M. F. (B)
Gray, Edward J. (B)
Littleford, J. W. (B)
Marra, Hiram E. (C)
Rountree, Leslie C. (C)

SANGAMON VALLEY

Raffety, H. W. (C)
Sadagopan, V. (D)

SHREVEPORT

Umphress, Neal (C)

STARK CENTRAL

Saurer, Russel F. (B)

SUSQUEHANNA VALLEY

McAlarney, James P., Jr. (B)

SYRACUSE

McWilliams, F. J. (C)

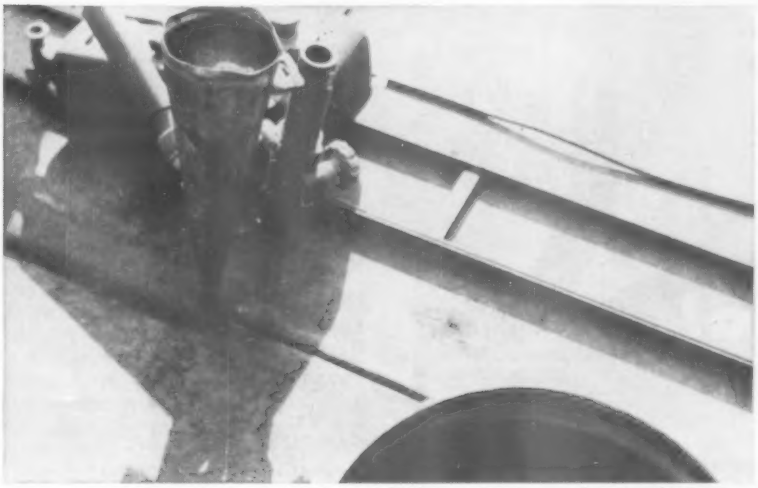
TULSA

Wainwright, Rex H. (B)

Lincoln

WELDYNAMICS

NEWS ABOUT ARC WELDING AT WORK CUTTING COSTS



A "Squirt" Welder welds heavy plate in 1/4 the time.

WAR AGAINST HIGH COSTS NETS BARGE BUILDER 75% BONUS

The Wiley Manufacturing Company of Fort Deposit, Maryland, builder of welded barges and large custom built cranes, initiated a cost reduction program that resulted in real savings.

Stanley Welsh, general superintendent, and J. J. Evans, general foreman, faced with ever rising labor costs, decided bold action was necessary if the company was to keep prices competitive. Since welding is the largest single operation in the Wiley yards it was only logical that they should look for a way to reduce welding costs first.

Enlisting the aid of Joe Gulley, a Lincoln welding engineer out of Lincoln's Baltimore office, the Wiley men began a detailed survey of their welding procedures and processes.

Mr. Gulley assisted Mr. Evans and his weldors to analyze the methods and electrodes used for welding sub-assemblies and for joining the sub-assemblies to the main structure. It was found that by positioning the smaller units iron-powder Jetweld electrodes could be used and speed increased considerably.

The jack-pot, though, was won by switching to semi-automatic for welding of heavy plate. By using a Lincoln "Squirt" welder propelled on a gas cutting buggy, Wiley is able to weld heavy plate, up to ¾ inch, in ¼ the arc time previously required to weld it manually.

Welded units form the barge on the ways.

Structural members are fabricated on the ground with Jetweld, then welded into sub-assemblies.

Jack Evans, General Foreman at Wiley, sparked a cost reduction program that succeeded.

Mr. Evans states that these savings are made even greater because very little plate preparation is necessary. Bevel is eliminated in plate up to ½" and weld cleaning is greatly simplified. The resulting welds are better, too, than can be made manually.

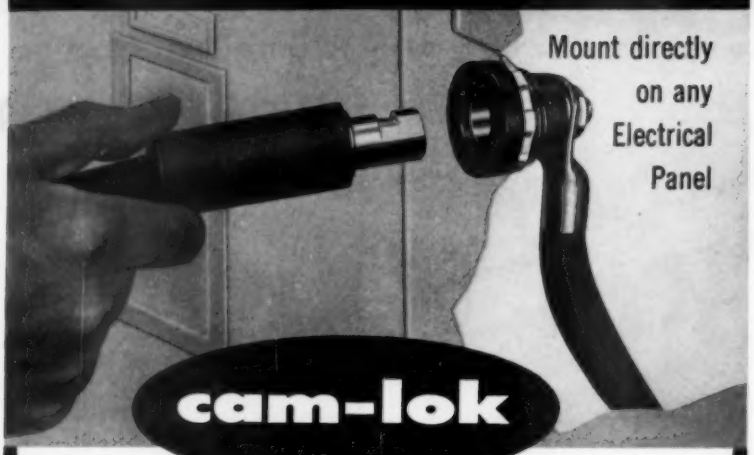
The result—a 75% saving in arc time on this operation!

Although no overall cost figures were immediately available, Mr. Evans estimated that they had been able to reduce total welding costs by at least one third.

The LINCOLN ELECTRIC CO.
Dept. 1951, Cleveland 17, Ohio
The World's Largest Manufacturer of Arc Welding Equipment

For details, circle No. 25 on Reader Information Card

New Hi-Impact Plastic Insulated
Panel Receptacles and Mating Plugs



Now, you can make fast, positive power connections to any metal panel or housing without special insulating materials. Simply punch out a hole and insert a Cam-Lok self-insulated Receptacle! Uses standard electrical lock-nuts, affords "dead-front" protection. Push in and twist Cam-Lok mating Plug and you've made a locked connection, which can be released quickly.

New Cam-Lok Receptacles eliminate costs of special insulating panels and reduce assembly time. Patented, high-pressure contact assures minimum resistance and heating.

Cam-Lok has a complete line of Receptacles and Plugs in many sizes and designs. Standard and special purpose Power Distribution Connections are available. Write today for new Bulletin No. 301.

"Dead Front" design for fast
direct mounting on . . .

• ELECTRICAL DISTRIBUTION PANELS • SWITCHGEAR
• BUS DUCT • JUNCTION BOXES
• WIREWAY or any electrical cubicle

A Complete Line of Welding Accessories and Special Power Distribution Connections

cam-lok DIVISION

EMPIRE PRODUCTS, INC.
P.O. BOX J-98
CINCINNATI 36, OHIO

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WESTERN MICHIGAN
Boettcher, Paul (C)
Olbrich, Edmund (B)
Wansak, Rudolph (B)

YORK-CENTRAL PA.
Baird, Ervin C. (C)

MEMBERS NOT IN SECTIONS
Artus-Martinelli, Italo (B)
Davalos, Guillermo F. (C)
Fisken, Gordon F. (B)
Jenkins, Clodwin C. (C)
Meister, Rolf H. (B)
Orr, Walter Lewis (B)
Ricci, Vittore (B)
Woodward, Dennis Howard (B)

Members Reclassified
During the month of January

FOX VALLEY
King, Robert E. (B to A)

HOUSTON
Liner, W. R. (C to B)
Rayfield, Robert N. (C to B)

IOWA-ILLINOIS
Dailey, Arthur E. (C to B)

MARYLAND
Bennett, Floyd K. (C to B)

SALT LAKE CITY
Braun, Louis A. (C to B)

SAN FRANCISCO
Burkhalter, Richard L. (D to C)

WASHINGTON, D, C,
Douglas, William P. (C to B)

YORK-CENTRAL PA.
Mianulli, Michael J. (B to A)

Don't Forget Your Hotel Reservation

Have you mailed your hotel reservation form for the Society's 40th Annual Meeting and Welding Exposition to take place in Chicago, Ill. Apr. 6–10, 1959?

If not, and you plan to attend this meeting, you should send your room requirements to the:

AWS-AIEE Housing Committee, c/o The Chicago Convention Bureau, Inc., 134 North La Salle Street, Chicago 2, Ill.

NEWS of the industry

Airco Starts Production at New Plant

The Air Reduction Sales Co. has announced the completion of a new facility for the production of oxygen and nitrogen at 1100 Packard St. in the Armourdale district of Kansas City, Kan.

Designed to expand capacity to serve users of industrial gases located within a 300-mile radius of Kansas City, the new plant makes high-purity oxygen and nitrogen.

Built by the Collins Construction Co. of Kansas City, the new plant replaces an Air Reduction facility at 1000 West 26th St., Kansas City, Mo., which has been closed. The Air Reduction district offices, storeroom and engineering services department remain at 2701 Warwick Trafficway, Kansas City, Mo.

Lincoln Pays Incentive Bonus

The employees of the Lincoln Electric Co. shared their annual incentive pay bonus on Dec. 5, 1958, marking the 25th anniversary of the first Lincoln bonus distribution in 1934. This year 1380 employees shared a total of $5,147,450. In 1934, 398 employees shared $131,785.

In addition to the incentive bonus, the company has also purchased retirement annuities for all employees each year since 1936. This year the company spent $850,000 for annuities.

Since 1934 Lincoln employees have earned a total of $86,461,105 in cash bonuses and annuities in addition to their regular pay.

Incentive pay is a feature of Lincoln Electric's philosophy of incentive management with which the company is operated. This philosophy enlists the efforts of workers to do their best by recognizing individual effort strictly on the basis of merit. Pay, promotion, and other recognitions are in direct proportion to how well each person performs.

Liquid Carbonic Acquires Industrial Air Products

Acquisition of Industrial Air Products of the South was announced by Rex L. Nicholson, president of Liquid Carbonic Division of General Dynamics Corp.

The acquirement includes two plants, with a total of 60 employees, manufacturing oxygen and acetylene, in New Orleans, and Pescaycula, Miss.

Warehouses are located in New Orleans, Baton Rouge, Houma and Morgan City, La.

Air Products of the South will be under the management of Liquid Carbonic's Southern Region with headquarters at Atlanta, Ga. Ralph Brown was appointed sales manager of the New Orleans operation.

Liquid Carbonic now operates forty-eight compressed gas plants and a hundred warehouses in the United States and Canada.

P & H Names Texas Distributors

Harnischfeger Corp., Milwaukee, Wis., announces the following appointments in Texas to handle the sales of P&H welders, electrodes and positioners in adjacent trade areas: Compressed Gas Sales Co., Wichita Falls; Compressed Gas, Inc., Abilene; and Four R Industrial Supply Co., in Borger and Pampa

OKIVA Acquires Assets of O.K.I. Industrial Sales Div.

Since March 1937, O.K.I. Welding Supply Co., 1630 Walnut St.,

COMING EVENTS

A Calendar of Welding Activity

AWS National Meetings

40th Annual Meeting:
April 6–10, 1959. Hotel Sherman, Chicago, Ill.

Seventh Welding Show:
April 7–9, 1959. International Amphitheatre, Chicago, Ill.

1959 National Fall Meeting:
September 28–October 1. Sheraton Cadillac Hotel, Detroit, Mich.

41st Annual Meeting and Eighth Welding Show:
April 25–29, 1960. Biltmore Hotel, Los Angeles, Calif.

NEMA

March 12, 1959. Arc Welding Section Quarterly Meeting, Pittsburgh, Pa.

Western Metals Exposition

March 16–20, 1959. Pan-Pacific Auditorium and Ambassador Hotel, Los Angeles, Calif.

Fifth Nuclear Congress

April 5–10, 1959. Public Auditorium, Cleveland, Ohio.

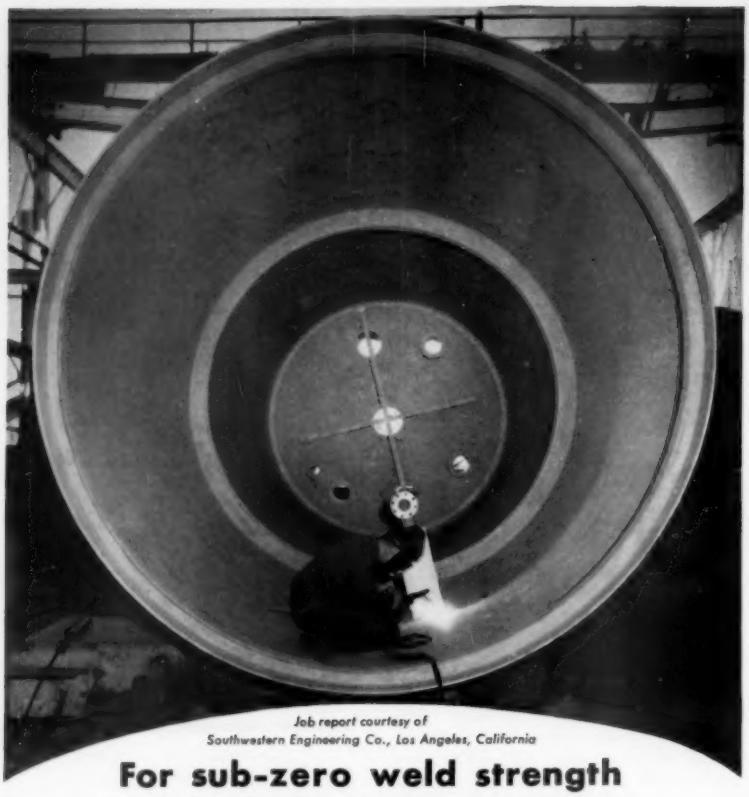
NWSA

May 4–7, 1959. Annual Meeting. Fairmount Hotel, San Francisco, Calif.

DIVISION

CINCINNATI 36, OHIO

For details, circle No. 31 on Reader Information Card



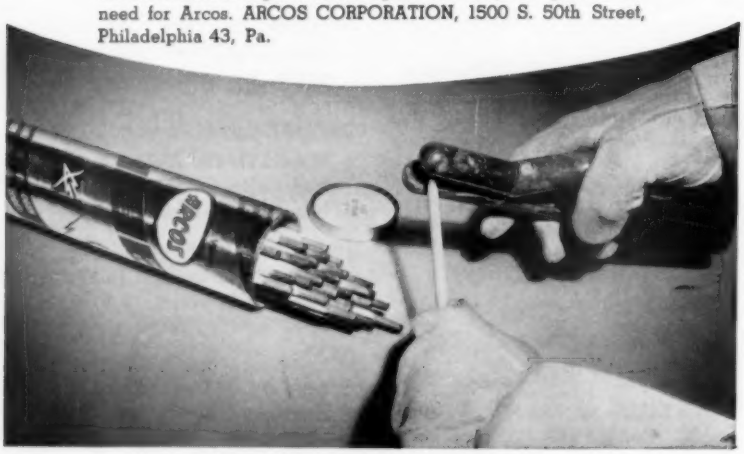
Job report courtesy of
Southwestern Engineering Co., Los Angeles, California

For sub-zero weld strength in missile fuel storage tanks

WELD WITH ARCOS

STAINLESS ELECTRODES

When completed, this tank will hold a liquid propellent fuel under 125 lbs. psi. Service temperatures will range from plus 200°F down to *minus* 300°F. The customer selected type 321 stainless for the vessel. To assure required impact strengths at extreme temperatures, Arcos STAINLEND 19/9Cb electrodes were recommended. This top quality weld metal joins the heads, shell seams, fittings and all attachments. Again—the tougher the test, the greater the need for Arcos. ARCOS CORPORATION, 1500 S. 50th Street, Philadelphia 43, Pa.



For details, circle No. 33 on Reader Information Card

Cincinnati, Ohio, has operated as factory representatives and wholesale distributors of welding and safety equipment and supplies.

In addition to the above wholesale activities, the O.K.I. Welding Supply Co. has operated an Industrial Sales Division which has sold direct to the user in the greater Cincinnati area.

Effective Jan. 1, 1959, the O.K.I. Welding Supply Co. has divested itself of all direct-to-the-user sales and from now on will limit its sales operations entirely to distributors and dealers.

Accounts receivable, good will, and other assets of the Industrial Sales Division of O.K.I. Welding Supply Co. have been acquired by OKIVA, Inc., an Ohio corporation with headquarters in Cincinnati.

Officers of OKIVA, Inc. are: J. Samuel Fry, president and treasurer; Thomas J. McManus, vice-president; and Robert E. Hamrock, secretary.

Ampco Names New Distributors

Lewis Industrial Supply Co., 938 South Fifth St., Louisville 3, Ky., has been appointed a distributor of Ampco resistance-welding products and accessories.

This new distributor will handle the Ampco-Weld stock line of tips, holders and seam welder wheels as well as such resistance-welding accessories as vise grip pliers, shut-off couplings, adaptors, tip dressing files, dies and seam-welder shafts and bearings.

Effective immediately, Ampco Bronze Weldrod products will be distributed by American Oxygen Service Corp., 111 South Fourth St., Harrison, N. J. They will handle Ampco-Trode, Ampco-Trode "AC" and Phos-Trode electrodes, filler rod and spooled wire, in addition to Ampco-Braz gas welding and brazing rods.

M & T Reports Third Quarter Gains

Net sales and earnings of Metal & Thermit Corp. for the three months ended Sept. 30, 1958 were the best for any quarter thus far this year, according to H. E. Martin, president.

Third quarter operations followed closely predictions made previously and gains in September came precisely on schedule, he said. With the national business picture today definitely changing for the better, "We can be expected to enjoy our

nizing individual effort strictly on the basis of merit. Pay, promotion,

Since March 1937, O.K.I. Welding Supply Co., 1630 Walnut St.,

Fairmount Hotel, San Francisco, Calif.

share of the general improvement," Mr. Martin said.

Net sales for the third quarter amounted to $8,944,235, compared with $8,403,355 in the three months ended June 30th and with $10,571,280 in the third quarter of 1957. The improvement shown in the September quarter followed a decline of less than six-tenths of 1% in the second quarter, as compared with the first.

Film on Inert-Gas Welding

Linde Co., Division of Union Carbide Corp., 30 E. 42nd St., New York 17, N. Y., has produced an 8-min film in sound and color which depicts an orientation in inert-gas-shielded arc welding. This film is available at no charge from any Linde office.

Gregory Sales Show Gain in October

Gregory Industries, Inc., manufacturer of Nelson stud welding products and Bulldog concrete fastening devices, has reported net earnings of $155,302 or 50 cents per share for the six months ended Oct. 31, 1958. This compares with earnings of $180,496 or 58 cents per share on an equivalent number of shares during the same period last year.

George E. Gregory, president, in an interim report to shareholders, reported that October sales reached the highest level in the company's history and sharply reversed the trend prevailing in the previous twelve months, with the result that second quarter earnings advanced to 30 cents per share as compared with 20 cents in the preceding quarter.

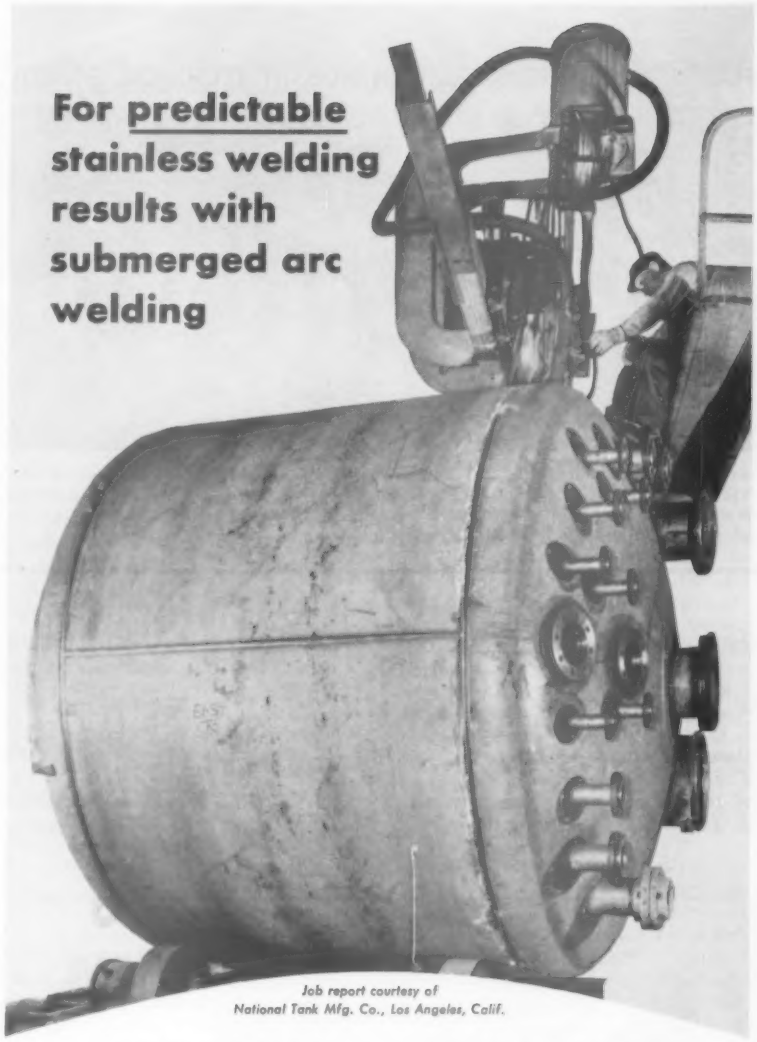
Amperex Appoints Representatives

Frank Randall, president of Amperex Electronic Corp., Inc., Hicksville, Long Island, N. Y., manufacturers of electron tubes and semiconductors for communications, announces the appointment of two firms as manufacturer's representatives for the Arkansas, Louisiana, Oklahoma and Texas areas.

One firm, Crockett-Lund & Co., 2204 Griffin St., Dallas, Tex., will cover distributors in the four-state area.

The other firm, Norvell Associates, 3603 Lemmon Ave., Dallas, Tex., will service equipment manufacturers in the same area.

For predictable stainless welding results with submerged arc welding



Job report courtesy of National Tank Mfg. Co., Los Angeles, Calif.

use ARCOSITE BONDED FLUX

This 4,000-gallon tank for a resin reactor will handle highly corrosive material at temperatures of 500° to 600°F. Stainless top and bottom heads of type 316L were submerged arc welded to the body with Arcosite Flux and Arcos Chromenar Stainless Wire. This combination gives the proper weld metal chemistry for the needed corrosion resistance and an economical solution to the problem. ARCOS CORPORATION, 1500 S. 50th Street, Philadelphia 43, Penna.

For details, circle No. 35 on Reader Information Card

For details, circle No. 33 on Reader Information Card

PROFESSIONAL ENGINEERS VISIT HOBART TECHNICAL SCHOOL

Forty-two members and guests of the Mid-Western Chapter of The Ohio Society of Professional Engineers held their November meeting at the new Hobart Brothers Technical School, Troy, Ohio. Speaker for the evening was Howard B. Cary, director of the school, who talked about welding-operator training and qualification procedures

Plan to Attend

AWS 40th Annual

Meeting

and

7th Welding Show

April 6–10

Chicago, Ill.

Harnischfeger Appoints Distributors

Harnischfeger Corp., Milwaukee, Wis., announces the appointment of two new distributors of its complete welding machine line in Virginia—Welder Supply Co., Inc., of Richmond, under the direction of J. C. Lucy, Jr., and Brammer Welding Supply Co., of Lynchburg with J. H. (Billy) Brammer at the helm.

Wallace Supplies to Represent Cincinnati Firm

The Wallace Supplies Manufacturing Co. announces its appointment as national representative and distributor of Hosking Tapered Diamond Slip Fittings, Cincinnati, Ohio.

The Wallace Co., in addition to stocking and selling fittings nationally, will have exclusive distributorship in the north-central area of the United States.

NEW TOP POSITIONS OPEN IN OUR RESEARCH GROUP

I am seeking two new important members for our Welding Research Staff. I am particularly interested in meeting and discussing these opportunities personally with prospective candidates.

HEAD OF BASIC RESEARCH

One opening requires a person capable of leading our basic research program throughout our worldwide organization. If desired, I offer the opportunity to the successful applicant of residing in French Switzerland and working in our affiliated research center in Lausanne. The most modern and attractive laboratory facilities are available both in Lausanne and Flushing, New York.

This gentleman would be in charge of our international research group and would work directly with me. He would be provided also with the opportunity to have contact with all phases of marketing and field servicing.

RESEARCH & DEVELOPMENT CHEMIST

The other excellent position we have open is for a chemist who has some research and/or development experience, and who is also experienced in actual production problems. The selected person would be offered the opportunity to head one of our overseas manufacturing units.

This independent and challenging position therefore calls for technical ability and an outstanding sense of responsibility.

Our organization is well-known, and has been exceedingly successful in developing leadership in our field. Many important projects are under study, and in development stages, which offer constant challenge to our research staff.

Our organization is progressive both in its technical outlook and in its relationship with its personnel. You are offered excellent remuneration and the opportunity for advancement. Applicants are requested to submit handwritten resumes, supplying information relative to work accomplished, personal data covering date and place of birth, educational background, languages spoken and written, as well as a recent photograph.

I will be interested in hearing from you, and would appreciate if you would address all replies directly to my attention.

Rene D. Wasserman, President
Eutectic Welding Alloys Corporation
40-40 172nd Street
Flushing 58, New York

will service equipment manufacturers in the same area.

For details, circle No. 35 on Reader Information Card

PERSONNEL

Lenhard Named President

R. E. Lenhard AWS, executive vice-president of Air Reduction Sales Co., the industrial gases and welding products division of Air Reduction Co., Inc., has been appointed president of that division. He succeeds J. H. Humberstone AWS who, as vice-president of Air Reduction Co., Inc., will devote full time to corporation affairs.

Gannett Retires

J. K. Gannett AWS retired on January 1st, after 43 years with the Austin Co. and fifteen as its vice president in charge of all engineering and research.

A 1910 civil engineering graduate of the University of Michigan who is credited with many important "firsts," Mr. Gannett received a citation in 1953 as a Distinguished Alumnus "in recognition of his outstanding achievements and of his contributions to the development of the field of engineering."

Joining Austin in Cleveland in 1915 as assistant chief engineer, he went to Paris in 1918 in charge of foreign operations.

From 1928 to 1944 he was located in New York as vice president in charge of all Eastern operations.

In 1944 Mr. Gannett was moved to the national headquarters in Cleveland, elected a director of the company and vice president in responsible charge of all engineering and research throughout this international engineering and construction firm.

Following an extended trip to Europe in 1950, he launched the company on a long-range inquiry into the use of prestressed concrete beams in building construction, at a time when their only use in this country had been in two bridges. Under his direction a series of full scale tests with prestressed beams and girders at Austin's Fabricating Division led to the company constructing the first industrial building in this country incorporating prestressed girders.

Grover Elected Chief Officer

Clayton D. Grover AWS, president of Whitehead Metals, Inc. since July 1954, has been elected chief officer of the company, it was announced following a recent meeting of the Board.

Mr. Grover was born in Mansfield, Mass. After graduating from the Massachusetts Institute of Technology with an S.B. degree in 1922, Mr. Grover taught chemistry for several years at the University of Rochester, N. Y. In 1925 he joined the International Nickel Co., Inc., at the company's Huntington Works Physical Laboratory, at Huntington, W. Va.

He was transferred in 1927 to the Boston Office of the Whitehead Co. In 1929 he became manager of Whitehead's Buffalo Branch and in 1934 joined the Technical Sales Department in New York. Mr. Grover was made assistant to the president of Whitehead in 1939, vice president in 1941, and president in 1954. He has been a director of the company since 1949.

R. E. Lenhard

Thomas M. Bohen, who has been associated with Whitehead since formation of the original company in 1914, and who served as its president from 1939 to 1954, when he became chairman, has been elected honorary chairman of the Board of Directors.

The name of the company, which is an affiliate of International Nickel, was recently changed from Whitehead Metal Products Co., Inc., to Whitehead Metals, Inc.

Waidelich Made Director

Stockholders of the Austin Co. have elected three new directors: L. Paul Gilmore, vice president-secretary-treasurer of the company; James R. Stewart, general counsel; and A. T. Waidelich AWS, vice president, who was also elected director of engineering and research, succeeding J. K. Gannett (who has retired as an officer and director). All are residents of Cleveland.

Mr. Waidelich has been vice president and manager of research since 1949. He joined the Austin organization as a structural designer in its New York office in 1936 following several years on the structural engineering faculty at Massa-

J. K. Gannett

C. D. Grover

A. T. Waidelich

First Order for All-Welded Aluminum Hulls Convinces Boat Builder:

"ALUMINUM IS EASY TO WELD"

"Only four months for designing and building 72 all-welded aluminum-hulled boats for the purse seining fishing fleet left us no time for welding mistakes," says Mr. Donald C. Hankin of RTC Shipbuilding Corp., Camden, N. J. "These boats take tremendous punishment from pounding seas, rugged weather and from the drag of tons of menhaden fish against the hulls. This means that every weld has to be perfect.

"Our only previous experience with aluminum welding had been a trial order for two boats of the same type. Our customer was so impressed with their performance that he immediately ordered a whole fleet.

"Prior to building these test boats, three of our welders had received training at Alcoa's New Kensington job shop. Now this really paid off. We found that aluminum could actually be welded at a faster rate than steel, and with relative freedom from warping and distortion. Aluminum's lighter weight eased handling problems and speeded assembly. As a result, the order was completed on schedule and the customer reports no trouble with the aluminum hulls."

This is only one example of the many exciting possibilities in welding, brazing and soldering Alcoa® Aluminum and its alloys. Alcoa's research in alloys, welding techniques and joining methods can help you all the way from design to production. For more information, contact your Alcoa sales office. For welding materials, call your local Alcoa Distributor listed at the right. And for booklets and films that show how easy it is to weld, braze and solder aluminum, write Aluminum Company of America, 1762-C Alcoa Bldg., Pittsburgh 19, Pa.

Your Guide to the Best in Aluminum Value

ALCOA ALUMINUM

For Exciting Drama Watch "Alcoa Theatre," Alternate Mondays, NBC-TV, and "Alcoa Presents," Every Tuesday, ABC-TV

For details, circle No. 37 on Reader Information Card

Want technical help in welding, brazing or soldering aluminum? Contact your Alcoa sales office, listed under "Aluminum" in the Yellow Pages of your phone book.

For immediate delivery of Alcoa welding products, call your Alcoa outlet listed below. He carries a complete range of alloys and sizes.

ALABAMA
Birmingham
Hinkle Supply Co.

CALIFORNIA
Los Angeles
Ducommun Metals & Supply Co.
Pacific Metals Company, Ltd.
San Francisco
Pacific Metals Company, Ltd.

COLORADO
Denver
Metal Goods Corp.

CONNECTICUT
Milford
Edgcomb Steel of New England, Inc.
Windsor
Whitehead Metals Inc.

FLORIDA
Jacksonville
The J. M. Tull Metal & Supply Co., Inc.
Miami
The J. M. Tull Metal & Supply Co., Inc.
Tampa
The J. M. Tull Metal & Supply Co., Inc.

GEORGIA
Atlanta
The J. M. Tull Metal & Supply Co., Inc.
Southern Oxygen Co.

ILLINOIS
Chicago
Machinery & Welder Corp.
Steel Sales Corp.

KANSAS
Wichita
Metal Goods Corp.

KENTUCKY
Louisville
Williams and Co., Inc.

LOUISIANA
New Orleans
Metal Goods Corp.

MARYLAND
Baltimore
Southern Oxygen Co.
Whitehead Metals Inc.
Bladensburg
Southern Oxygen Co.

MASSACHUSETTS
Cambridge
Whitehead Metals Inc.

MICHIGAN
Detroit
Steel Sales Corp.

MISSOURI
Kansas City
Metal Goods Corp.
St. Louis
Metal Goods Corp.
Steel Sales Corp.

NEW HAMPSHIRE
Nashua
Edgcomb Steel of New England, Inc.

NEW JERSEY
Harrison
Whitehead Metals Inc.

NEW YORK
Buffalo
Whitehead Metals Inc.
New York
Whitehead Metals Inc.
Syracuse
Brace-Mueller-Huntley, Inc.
Whitehead Metals Inc.

NORTH CAROLINA
Greensboro
Southern Oxygen Co.

OHIO
Cincinnati
Williams and Co., Inc.
Cleveland
A. M. Castle & Co.
Williams and Co., Inc.
Columbus
Williams and Co., Inc.
Toledo
Williams and Co., Inc.

OKLAHOMA
Tulsa
Metal Goods Corp.

OREGON
Portland
Pacific Metal Co.
J. E. Haseltine & Co.

PENNSYLVANIA
Philadelphia
Edgcomb Steel Co.
Southern Oxygen Co.
Whitehead Metals Inc.
Pittsburgh
Williams and Co., Inc.
York
Southern Oxygen Co.

TENNESSEE
Kingsport
Southern Oxygen Co.

TEXAS
Beaumont
Big Three Welding Equip. Co.
Corpus Christi
Big Three Welding Equip. Co.
Dallas
Metal Goods Corp.
Texas Welding Supply Co.
Houston
Metal Goods Corp.
Big Three Welding Equip. Co.
San Antonio
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J. E. Haseltine & Co.
Spokane
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WISCONSIN
Milwaukee
Machinery & Welder Corp.
Steel Sales Corp.

chusetts Institute of Technology and two years as assistant professor of civil engineering at Robert College in Istanbul, Turkey.

An assistant director of research at the company's headquarters from 1941 to 1949, he played a leading role in development of the revolutionary H-section welded truss and directed more than a score of surveys and reports which provided the basis for postwar projects in which more than fifty million dollars was invested during a three-year period.

As manager since 1949 of Austin's research division, which guides engineering surveys and reports, plant location surveys, etc., in all parts of the country, Mr. Waidelich has been responsible for the development of special techniques for evaluating the relative merits of different locations, layouts and materials handling methods which appear to be best suited for the solution of immediate and long-range problems.

A native of Philadelphia, Mr. Waidelich was graduated from Drexel Institute of Technology (B. S.-C. E.), and subsequently received his Master's Degree at Massachusetts Institute of Technology. As a European traveling Fellow from MIT, he also spent a semester each at the technical institutes in Darmstadt and Zurich.

Gent Appointed by Alcoa

Appointment of George R. Gent AWS to the newly created post of manager of welding, brazing and soldering product sales, has been announced by Aluminum Company of America.

Mr. Gent will coordinate a program to utilize efficiently Alcoa facilities, to disseminate information about joining methods and materials, and to merchandise joining products and services.

Mr. Gent joined Alcoa in 1946 as a salesman in the company's York, Pa. sales office. Since 1953, he has served as assistant to Alcoa's manager of wire, rod and bar sales.

A native of Toledo, Ohio, he studied mechanical engineering at Michigan State University.

McElhoe Joins National Welding

Ernest L. Mathy AWS, president and general manager, announces that H. L. McElhoe has joined National Welding Equipment Co. as general manager of their Southern Sales Division. His responsibility will include the establishment of one or more strategically located warehouses and sales offices, factory approved repair depots, the acquisition and development of distributors, specialized sales and technical assistance to distributors and publicity and promotion of National equipment.

He has just completed eight and one-half years with the Smith Welding Equipment Corp. where he started as a factory representative and progressed up through Southern District Manager and the past year has held the position of Director of Training with that company.

Muller Appointed Vice President

Albert Muller AWS, assistant to the president of Air Reduction Sales Co., the industrial gases and welding products division of Air Reduction Co., Inc., has been appointed vice president of that division.

Albert Muller

Before joining Air Reduction in 1946, Dr. Muller was with the National Academy of Sciences, War Metallurgy Committee, Washington, D. C. Prior to joining the division in 1957 he was director of metallurgical research at the company's Central Research Laboratories, Murray Hill, N. J.

Nielsen Made District Manager

Rankin Manufacturing Co., Alhambra, Calif., announces the appointment of Clarence A. Nielsen to

Alfred Provencher

Carl Gage

Fred Flint

Tom Burke

Glenn E. Smith

the position of District Manager in charge of Ranite and Ranomatic hard-surfacing sales in the Northeastern section of the United States and Canada. Mr. Nielsen, whose appointment was effective Jan. 1, 1959, will make his headquarters in Cleveland, Ohio.

Mr. Nielsen, whose broad background of experience covers both shop and sales work, previously was affiliated with the Allison Co. of Bridgeport, Conn., and the P. R. Mallory Co. of Euclid, Ohio.

Provencher, Gage Named by Arcos

Arcos Corp., Philadelphia manufacturer of welding rods and electrodes, has announced changes in its sales department organization. Alfred "Pete" Provencher AWS, formerly New England district manager, has been appointed Chicago district manager. Carl Gage AWS has replaced Provencher as manager in New England.

Mr. Provencher headed the New England office in Boston for two years, and Mr. Gage has served in the Philadelphia area since 1952.

Appointments Made By Tweco

Tweco Products, Inc. announces the following changes in its territory assignments, effective Jan. 1, 1959. Fred Flint AWS will now serve as West Coast District Manager for the states of Arizona, California, Idaho, Montana, Nevada, Oregon, Utah and Washington. Tom Burke AWS assumes new responsibilities in an enlarged territory as District Manager of the North Central Territory covering Illinois, Indiana, Michigan, Wisconsin, Ohio, Kentucky, West Virginia and Western Pennsylvania. Glenn E. Smith AWS becomes District Manager of the South Central District covering New Mexico, Texas, Louisiana, Arkansas, Mississippi, Alabama and the city of Memphis, Tenn.

Kartalia Promoted by Square D

Mitchell P. Kartalia, manager of Square D Co.'s marketing division, has been elected a vice president, Gordon Patterson, president, has announced.

Mr. Kartalia will be responsible for all programs within the total marketing concept, including distributor relations, field office operations, national advertising, market research, product development liaison and export activities.

Mr. Kartalia, who prior to last July had been sales manager of Square D's distribution equipment division, makes his headquarters in the Detroit executive offices. A graduate of the University of Cincinnati, he joined Square D in 1940 as a sales application engineer and successively rose to various executive sales positions.

OBITUARY

Kenneth D. Bryant

Kenneth D. Bryant AWS, 42, originator of several marking devices and aligners for the welding and

Kenneth D. Bryant

pipe-line industries, died of a heart attack December 12th at his home.

"K.D.," as he was known throughout the industry, was president of Contour Marker Corp., Compton, Calif.

Ernest F. Meier

Ernest F. Meier, Technical Assistant to the general manager of the Glascote Corp., a division of A. O. Smith Corp., in Cleveland, Ohio, died Friday, Dec. 5, 1958, while boarding an airplane in Chicago.

Mr. Meier was one of the influential pioneers of welding in the St.

Ernest F. Meier

Louis area where he served as chief maintenance engineer in charge of welding during many of the thirty years he spent at Monsanto Chemical Co.'s first manufacturing facility, the John F. Queeny Plant in St. Louis, prior to his retirement in 1956. It was at this time that he joined the Glascote Corp. as an outstanding authority on maintenance and repair of glass-lined equipment.

Mr. Meier was a past chairman of the St. Louis Section of the AMERICAN WELDING SOCIETY. His last appearance was as panel moderator at a symposium on Problems of Welding Corrosion-Resistant Metals. The St. Louis Section has observed his passing with a resolution commemorating his valued services.

Arthur Ray McCall

Arthur Ray McCall died suddenly of a heat attack on December 24th in Findlay, Ohio.

For the past five years Mr. McCall has represented O.K.I. Welding Supply Co. in the northwestern area of Ohio and in the eastern section of Michigan. At the time of his passing he was 52 years of age.

Mr. McCall had been a lieutenant in the Michigan National Guard. He was a member of the Lake City, Mich., Masonic Blue Lodge No. 408; the Lions Club of Findlay, Ohio; and the North Central Ohio Section of the AMERICAN WELDING SOCIETY.

In addition to his duties with O.K.I. Welding Supply Co., Mr. McCall acted as a welding instructor in the extension evening welding classes held by the Findlay public schools.

Mr. McCall is survived by his wife and a son.

Clifford H. Murray

Clifford H. Murray died on November 26th at St. Vincent's Hospital in Worcester, Mass.

An employe of Pullman-Standard Car Mfg. Co. for 36 years, Mr. Murray had been retired since July 31, 1957. He started with the company in 1921 as an inspector and was subsequently appointed general foreman. In 1945 Mr. Murray was named assistant superintendent, a position he held until his retirement from the firm. He had received his engineering degree from the International Correspondence School in 1915.

An active member of the AMERICAN WELDING SOCIETY, Mr. Murray had served the AWS Worcester Section as chairman and secretary.

He is survived by his wife, mother, three daughters and nine grandchildren.

WELDING ENGINEER

The Armour Research Foundation has an opening for an experienced welding engineer. Applicants should have several years of experience in welding and brazing research with at least a B.S. degree in Welding or Metallurgy.

The Foundation is located on the campus of the Illinois Institute of Technology and encourages graduate engineering study through its educational program providing tuition free graduate study, in addition to offering competitive salaries and liberal benefits including generous relocation allowance and vacation program.

Please send complete résumé to:

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of Illinois Institute of Technology
10 West 35th Street
Chicago 16, Illinois

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Positions Vacant

V-368. Assistant Production Superintendent. Preferably a graduate mechanical or welding engineer with 5–10 years welding fabrication shop experience in miscellaneous heavy steel, aluminum and stainless-steel weldments. Experience in modern techniques and applications desired. Ability to organize and operate efficient shop very important. A large growing company offering an excellent future. Located in the middle west.

V-369. Research Engineer. College graduate with at least B.S. in engineering, for Research and Development Department of nationally known welding equipment manufacturing company located South Jersey within six miles of Philadelphia. Position basically research and development in arc, resistance and stored energy semiautomatic welding field. $6600–8400. Attractive direct and indirect benefits with organization with consistent growth record. Although advanced degrees or experience are not required, they will be considered in evaluating applicants. Our employees know of this opening.

WELDING ENGINEER

Welding section of Manufacturing Research and Process Department has excellent opportunity for college graduate with BS in engineering or science plus 3 years experience in welding. The applicant selected will conduct research and development programs in welding. Also act as consultant to engineering and apply welding processes for production. Experience in aircraft manufacturing preferred. Salary commensurate with experience and ability to work with high degree of independence.

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Abstracts of Current PATENTS

prepared by Vern L. Oldham

Printed copies of patents may be obtained for 25¢ from the Commissioner of Patents, Washington, D. C.

2,818,494—Welding Machine—Arthur A. Bernard and Richard A. Bernard, Chicago, Ill.

In this patent, arc-welding apparatus is provided in combination with a swingable support crane. A rotatable coil of electrode is attached to the crane with a support having pivot means permitting universal movement of the coil relative to the crane and a welding torch is mounted in fixed relation to the coil for receiving the electrode from the coil and directing it to a workpiece. The torch and coil are movable as a unit relative to the crane and maintain the desired fixed relation to provide only predetermined bending of the electrode during its feeding action. An electrode supply and feeding unit is attached to the crane and included motor feed means with the entire feeding unit being universally movable relative to the crane.

2,818,496—Welding Electrode—Howard C. Ludwig, Pittsburgh, Pa., assignor to Westinghouse Electric Corp., East Pittsburgh, Pa., a corporation of Pennsylvania.

Ludwig's patent relates to a consumable welding electrode and it includes a ferrous wire having a roughened surface. A thin layer of oxygen containing material is deposited on the roughened surface and it contains at least one oxygen containing compound of the group consisting of metal oxides, metal phosphates and metal carbonates. The electrode is adapted to provide just sufficient oxygen to maintain the arc stabilized without producing substantial oxidation of the work immediately adjacent to the end of the electrode which is being melted.

2,819,120—Flux-Feeding Systems for Electric Welding—Ernest Jeremy Hume, Carnegie, Victoria, Australia, assignor to Humes Ltd., Melbourne, Australia, a company.

Hume's patent is an apparatus for feeding flux powder from a storage hopper to the welding zone of electric arc-welding apparatus. Pump and piping means connect a storage hopper for flux powder to a feed hopper by a substantially closed air stream circuit. A dispensing vessel is disposed beneath the storage hopper for receiving flux powder therefrom and has ejector means associated therewith to deposit or eject the powder into a pipe in the pump and piping circuit for entraining flux powder in the air stream in such piping circuit.

2,819,379—Double-Pass Welding of Spiral Pipe—Allen Dale Wiley and Forest C. Bowman, Middletown, Ohio, assignors to Armco Steel Corp., Middletown, Ohio, a corporation of Ohio.

By this patented process, the strip from which a pipe is to be made is wound into a helix with an edge of the incoming strip meeting an edge of the first convolution at the top of the formed pipe. A first butt weld is formed at the top of the pipe slightly beyond a vertical axial plane through the pipe to secure the edges together, and a second weld is formed over the first weld at the top of the pipe slightly ahead of the point where the first weld crosses the said plane at a succeeding convolution.

2,819,381—Method of Welding—Arthur L. Lindow, Northfield, and Ian R. Sutherland, Solon, Ohio, assignors to the Cleveland Pneumatic Tool Co., Cleveland, Ohio, a corporation of Ohio.

The present patent relates to the upset welding of two pieces of metal and wherein complementary surfaces are formed on the metal pieces and such surfaces are plated with nickel. The plated surfaces are pressed together with sufficient force to upset the nickel and produce intimate contact over the entire area of engagement. Thereafter an electrical current is passed between the pieces while pressed together to heat the nickel and the portions of the pieces adjacent thereto until they weld together and the nickel fuses into the pieces.

2,819,382—Methods of an Apparatus for Welding Tapes Together to Form Bi-Metallic Stock for Electrical Contacts—Charles C. Yeale, West Chicago, Ill., assignor to Western Electric Co., Inc., New York, N. Y., a corporation of New York.

A flexible tape is welded to a rigid bar by advancing the bar past an electrode in continuous sliding contact therewith. A flexible tape is advanced into contact with the bar at a point beyond the initial contact of the bar and the electrode. A portion of the tape is backed with a movable electrode and potential differences applied between the electrodes for the desired welding action.

2,819,383—Method of Arc Welding Titanium—James H. Johnston, Cambridge, Mass.

In Johnston's new method, an arc is generated between a body of titanium and an electrode to form a molten pool and a shield of inert gas is maintained around the arc and pool. Thereafter, a consumable rod containing calcium is fed into the arc at such a rate that the amount of calcium vaporized will be at least sufficient to scavenge both the pool of metal and the atmosphere within the shield of gas to remove contaminants therefrom as compounds of calcium insoluble in molten titanium.

2,819,384—Lubricant Feeder for Welding Apparatus—Elliot C. Cornell, Jr., Cleveland, Ohio, assignor to the Auto, Arc-Weld Manufacturing Co., Cleveland, Ohio, a corporation of Ohio.

Cornell's patent relates to means for cleaning and lubricating an electrode wire prior to its passage through a tubular welding cable for welding action. The apparatus includes means for automatically supplying a lubricant to a lubricant chamber in the apparatus and other members are provided for removing small particles of metal on the electrode wire as it is moved through the lubricating means provided.

2,819,443—Direct-Current Arc-Welding Generator—William J. Greene, Scotch Plains, and Richard B. Steele, New Providence, N. J., assignors to Air Reduction Co., Inc., New York, N. Y., a corporation of New York.

This patented generator has a field circuit including a pair of main poles adapted to operate under conditions of substantial saturation and a pair of cross poles adopted to operate nonsaturated. An armature is present and a commutator is provided on the armature and a pair of load brushes are positioned on the commutator so that the voltage difference between the load brushes is dependent upon the flux in both the main and cross poles. An auxiliary brush is also provided and positioned on the commutator so that the voltage difference between the auxiliary brush and one of the load brushes is dependent upon the flux in the main poles. A winding is provided on at least one pole of each of the pair of brushes and the windings are connected in series between such brushes and a variable resistance is in series with such windings. Voltage-reponsive means are present to adjust the value of the resistance to maintain constant voltage between this one load brush and the one auxiliary brush.

2,819,517—Method of Welding Pipe Ends Together—Robert T. Pursell, Watertown, Mass., assignor to Stone & Webster Engineering Corp., Boston, Mass., a corporation of Massachusetts.

Pursell's welding method includes the steps of sealing a combustible imperforate baffle in each of two pipes to be welded together in end-to-end relationship at a point spaced from the ends thereof. These pipes are held in abutting relationship and an inert gas is introduced thereinto through an opening into the chamber defined by the baffles and intervening pipe parts. The pipe ends are then welded to each other and the welded pipe ends are heated to burn the combustible baffles therefrom.

2,820,136—Method for Resistance Welding Blind Locations with Expendable Electrodes—Monroe H. Bester, Whittier, Calif., assignor to North American Aviation, Inc.

The present patent relates to the fabrication of a metal sandwich and it includes placing supports on a first metallic member that forms one face of the sandwich, and a sandwich core is placed on these supports. Other means lock the core and supports and sandwich metallic member together and the core is welded to depressions provided in the first metallic member. A second metallic member forming the other face of the sandwich is placed on the core and portions of the core are welded to the second metallic member where the supports contact the core. Thereafter the supports are removed from the sandwich.

2,820,427—Welding Back-up Assembly—John J. Chyle and Michael W. Zimmermann, Milwaukee, Wis., assignors to A. O. Smith Corp., Milwaukee, Wis., a corporation of New York.

The patented assembly is applied to the underside of the seam adjacent the edges of two metal articles that are to be welded together. The assembly includes glass sheet aligned beneath the seam to support the molten weld metal, and heat resistant pressure sensitive adhesive tape is applied to the under surface of the glass sheet and extends laterally from the sheet to be secured to the articles to hold the glass sheet in position beneath the seam to be welded.

2,824,948—Method of Electric Arc-Welding—Paul Christiaan van der Willigen and Henri Bienfait, Eindhoven, Netherlands, assignors, by mesne assignments, to North American Philips Co., Inc., New York, N. Y., a corporation of Delaware.

In this new arc welding method, a welding wire is fed to the workpiece and approximately 100% carbon dioxide is supplied adjacent the arc. This weld wire is made from iron alloyed with at least 0.3% by weight of manganese and at least 0.3% by weight of a strong reducing metal.

2,824,949—Hydraulic Control Device for Resistance Seam-Welding Machines—Milan Vitavsky, Bratislava, Czechoslovakia.

The present patent relates to a machine having rotatable welding rollers provided therein. Pressure fluid operated motor means are present for moving the welding rollers toward each other to press an object to be welded therebetween. The patent relates to special controls for the operation of the motor means and associated portions of the apparatus

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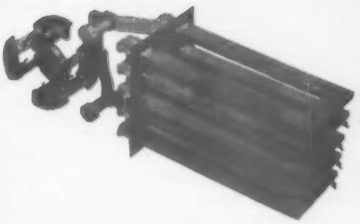

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"In two or three hours with these machines, we can perform radiography jobs which would have taken 35 to 40 hours with conventional X-Ray equipment," says Mr. Frank Steele, Director of Non-Destructive Testing of Froehling-Robertson, Inc., Richmond, Virginia. Mr. Steele's company has four Nuclear Systems Model 10 Iriditrons in constant use, and plans to buy more.

This is a company whose sole business is testing. Time and cost are naturally of utmost importance . . . and Froehling-Robertson, Inc. has found that it can perform its services faster and better for the company's many customers through the use of fast, portable, economical, safe Nuclear Systems equipment. "Companies have been amazed by the speed with which we can perform our testing. Production has greatly increased," adds Mr. Steele.

There's a Nuclear Systems radiography machine to fit your testing requirements . . . and budget. For information about it, write any of our sales offices.

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A DIVISION OF THE BUDD COMPANY, Philadelphia 32, Pa.

Budd

For details, circle No. 41 on Reader Information Card

New Literature

Wall Chart

A new welding-shop wall chart of 89 problem-solving, specialty alloys and fluxes is now available from All-State Welding Alloys Co., Inc., White Plains, N. Y. Copies can also be obtained from welding supply distributors throughout the country. The chart, 18 x 22 in. on heavy coated paper, sorts out the criteria which always should be taken into consideration in choosing an alloy for welding shop application. Maintenance, production and installation jobs are covered. On aluminum and aluminum alloys, cast iron, copper and copper-bearing alloys, magnesium, Monel, nickel, stainless steel, steel, zinc base die cast, etc.

The select-a-rod data are intended to enable the welder to adopt best alloy and procedure for cold repairs without dismantling; joining dissimilar metals; impact, wear and corrosion-resistant overlays; cutting, gouging, chamfering without oxygen; and making strong joints at extremely low heat.

For your free copy, circle No. 2 on Reader Information Card.

Pressure Regulators

A new 36-page catalog covering Air Reduction's complete line of cylinder, manifold and station pressure regulators is now available from the company.

The illustrated booklet contains flow and pressure specifications, as well as inlet and outlet connection dimensions, for each regulator. Adapters, station valves, flowmeters, hose connections and pressure gages are also described in detail.

For your free copy, circle No. 4 on Reader Information Card.

Alloy Data

An alloy that has built a reputation as being one of the most universally corrosion-resistant alloys available is the subject of a newly printed, 16-page booklet from Haynes Stellite Co., Division of Union Carbide Corp., Kokomo, Ind.

This piece of technical literature combines the latest data pertaining to "Hastelloy" Alloy C under one cover. Chemical, physical and mechanical properties, along with a guide to corrosion resistance, are presented through the use of charts and graphs. Valuable data on the excellent high-temperature properties of Alloy C are also included.

For your free copy, circle No. 6 on Reader Information Card.

Brazing Cement

A new 2-page $8^1/_2$ x 11 in. two-color engineering data sheet (No. 7) discussing Nicrobraz cement for use in applying brazing alloys for high-temperature service is now available from Stainless Processing Division, Wall Colmonoy Corp., 19345 John R. St., Detroit 3, Mich.

Composition, properties and uses of the new cement are described. Included is a chart showing approximate Zahn viscosity numbers for 6 different thicknesses of Nicrobraz cement.

Use of the Nicrobraz cement as a binder for Nicrobraz "White Stop-Off" is also discussed.

For your free copy, circle No. 8 on Reader Information Card.

Resistance Welding of Aircraft

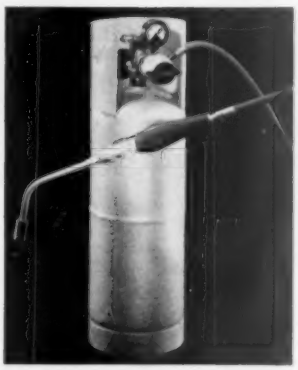
Sciaky Bros., Inc., 4915 West 67th St., Chicago, Ill., announces the release of a pictorial engineering report—"Overhaul and Repair of Jet Engines and Airframes."

The basic point of this report is to emphasize basic maintenance and repair by resistance welding of aircraft components and structures originally fabricated with resistance welding. It is also pertinent to call attention to the many instances where the resistance-welding process does a better and simpler job of repairing assemblies that for one reason or another were originally riveted, fusion welded, etc. Particular attention is directed to the free use of ingenuity in applying spot, seam and flash-butt resistance welding.

For your free copy, circle No. 10 on Reader Information Card.

6-Lb Propane Cylinder

A new 6-lb capacity propane cylinder, designed for use with a wide variety of standard and special valves for any type of propane service, can now be obtained from Linde Co., Division of Union Carbide Corp., New York 17, N. Y.



The new cylinder can be used with all LP-gas soldering, heating and brazing equipment, and can be adapted for trailer use where a small capacity cylinder is desired. In short, it is intended to meet the demand for a small-sized, lightweight and portable cylinder.

The P-6, as it is called, can be utilized for liquid or vapor service in the vertical or horizontal position, depending upon the type of valve selected. It weighs only 14 lb, complete with valve, and has an over-all length of 20 in. and a diameter of $6^3/_{16}$ in.

For your free copy, circle No. 12 on Reader Information Card.

Silver Brazing of Cast Iron

Handy & Harman, 82 Fulton St., New York 38, N. Y., has published "Brazing News #80," a 4-page pamphlet in color, which emphasizes the importance of cast iron as an assembly metal. The literature points out the ease by which cast iron can be joined to other metals by silver brazing. Photographs illustrate possible applications and a table lists the characteristics of principal types of cast iron.

For your free copy, circle No. 14 on Reader Information Card.

Aluminum Welding Wire

Kaiser Aluminum's inert-gas welding wire is the subject of a new booklet released by Kaiser Aluminum & Chemical Sales, Inc., describing the process and listing availabilities.

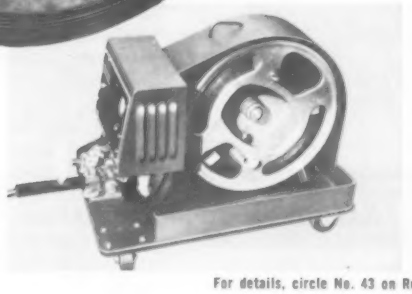
"Stoody SEMI-AUTOMATIC Hard-Facing *Splits my work in half!"*

Here's a welder's own words about semi-automatic hard-facing on roll crushers..."I can do as much work in 4 hours with Stoody Semi-Automatic Hard-Facing as I used to do manually in 8 hours. The metal doesn't get as hot, and I can make a higher, wider, bead —with less effort. You just can't beat these machines for hard-facing no matter how hard you try."

If you want to cut down on your own work, if you want to *accomplish more* in a given time, you should try Stoody Semi-Automatic Hard-Facing!

We'll be glad to arrange a free demonstration in your plant, hard-facing *your* parts. You be the judge!

Stoody semi-automatic wires are supplied in continuous coils and can be fed through most standard types of semi-automatic welding machines. A wide variety of alloy types cover all job requirements.



Literature is available.
Ask your nearest Stoody Dealer or write direct to the company.

STOODY COMPANY

11986 East Slauson Avenue • Whittier, California

For details, circle No. 43 on Reader Information Card

Known by the brand name "King," Kaiser Aluminum's spooled electrode for inert-gas welding is a continuous, consumable electrode.

The booklet also describes "King" filler rod used for inert-gas tungsten-arc welding. Full details concerning availabilities, packaging and care of welding wire are included.

For your free copy, circle No. 16 on Reader Information Card.

Abrasive Catalog

The Thermacote Co. in Pasadena, Calif., announces a new grinding-wheel and abrasive catalog which includes approximately twice as many items as shown in their old Thermo-Cut Grinding Wheel catalog.

For your free copy, circle No. 18 on Reader Information Card.

Surfacing

Volume 17, No. 8 of "Fusion Facts," published by Stoody Co., Whittier, Calif., contains eight articles, two of which stress the profits realized from the application of practical ideas, as illustrated in the rebuilding of portable crushers. Other articles, including "Machining Rebuilt Tractor Rolls" and "Does it Pay to Hard-Face Inexpensive Parts?" also appear in the Fall 1958 issue.

For your free copy, circle No. 22 on Reader Information Card.

Resistance Welding

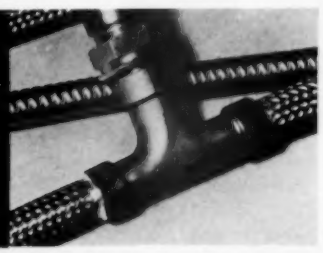
A 28-page bulletin "Federal PP-54" issued by the Federal Machine and Welder Co., Warren, Ohio, illustrates and describes resistance welding in all phases, spot welding, projection welding, seam welding, flash welding, etc.

This bulletin gives the user a good working knowledge of the basic principles of resistance welding; it includes a resistance welding formula, data on how to calculate welding pressures, time in cycles, current in secondary amperes, tip diameter, projection specifications, seam welding charts and flash welding information, also other pertinent data on welding, mild steel, high-carbon steel, ternplate, tin plate, galvanized steel, stainless, copper, aluminum, etc.

For your free copy, circle No. 32 on Reader Information Card.

SOLDERING PROBLEM?

stainless to aluminum?
aluminum to copper?
cast iron to steel?



BOEING 707 Landing Gear Harness
Braided stainless steel wire and flexible conduit had to be joined to cast fittings. Brazing burned the fine wire. ALL-STATE had a special solder which solved the problem. (See #430, below.)

You get high strength with ALL-STATE special solders

#7 Special solder for cast iron 450-600°F. Withstands 1000 psi P.

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#39 Special solder to join all types of aluminum for both build-up (450°F) and capillary flow (650°F) – with or without flux. 8000 psi T.

#55 Newly developed aluminum "rubbon"® solder – NO FLUX – 705°F – 20,000 psi T. All aluminums.

#105 Special medium temperature alloy for both ferrous and non-ferrous metals (640-740°F) – to 25,000 psi T.

#107 The finest made to join aluminum to steel, copper and brass – or to each other (480-600°F) – to 25,000 psi T.

#430 NO LEAD, NO ZINC or CADMIUM – develops tensile strengths of 10,000 to 28,000 psi on stainless and dissimilar metals. For soldering iron at a low 430°F.

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ALL-STATE WELDING ALLOYS CO., INC., White Plains, N. Y.
Call WHite Plains 8-4646 or write for nearest distributor

For details, circle No. 45 on Reader Information Card

Soldering of Titanium

Literature, describing a filler metal, Curtisol, and a flux, Curtiflux, for low-temperature, high-strength titanium torch soldering, is now available from Curtiss-Wright Corporation, Princeton Division, Princeton, N.J. Among the recommended joining applications for the new filler metal-flux combination are small titanium parts to large castings, field fabrication of titanium tubing and structural reinforcements in aircraft fuselages.

For your free copy, circle No. 24 on Reader Information Card.

Aircraft Welding Guns

A. P. Seedorff & Co., Inc., 4617 Cecilia St., Bell, Calif., have issued 4-page Bulletin No. 580 which describes the firm's miniature portable gun welders. Designed for spot welding, tacking and tack brazing light stainless-steel structures, honeycomb panels, face sheets and skins, and core splicing, the guns are reportedly manufactured to aircraft specifications. One push-type hand gun and two air-operated pincer-type guns are available. The manufacturer also offers a portable power and control unit.

For your free copy, circle No. 26 on Reader Information Card.

Packaged Production Lines

The November 1958 issue of "Tips and Dies," Vol. 3, No. 4, is available from the Federal Machine and Welder Co., Warren, Ohio. In color, the four-page pamphlet describes and illustrates several automated lines and modern methods for mass production of fabricated parts.

For your free copy, circle No. 28 on Reader Information Card.

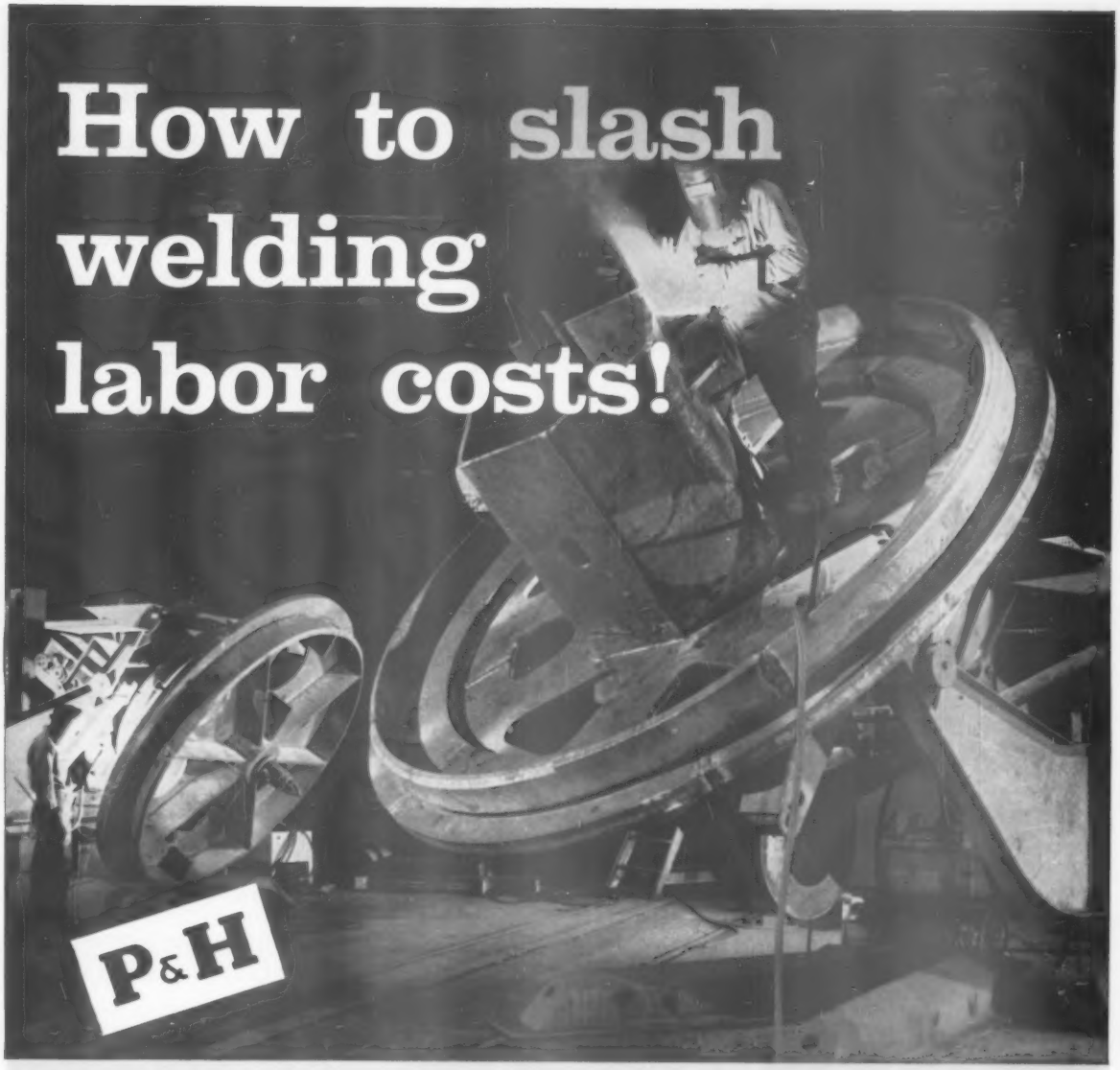
High-Pressure Gas Cylinders

Facts about Hackney high-pressure gas cylinders for oxygen and other industrial and medical gases are contained in a new bulletin released by Pressed Steel Tank Co., Milwaukee, Wis.

In addition to facts about the range of cylinder sizes, capacities and ICC specifications, the bulletin stresses the weight-saving value of seamless cold-drawn cylinders—important in considering means of lowering shipping costs. Although lightweight, with uniform side-wall thickness, strength and capacity, Hackney high-pressure cylinders reportedly comply with ICC safety specifications.

For your free copy, circle No. 30 on Reader Information Card.

How to slash welding labor costs!



Mechanize your weldment handling with P&H Welding Positioners

P&H Welding Positioners can often cut labor costs in half by providing faster, safer, *mechanized* weldment handling. With these modern machines, operators merely press a button to quickly spot the work so that all welds are made downhand — in the natural position.

Downhand welding pools more evenly, permits the use of larger, "hotter" rods — frequently cuts the number of passes from 3 to 1.

As a result, you get more arc-time *plus* better welds. Your weldors turn out more work each day and like it — they don't have to work in cramped, awkward positions that reduce efficiency. You eliminate waiting for cranes, and the use of extra helpers for repeated repositioning.

These money-saving machines are available from P&H with full 360° table rotation, 135° tilt, and power elevation even under capacity loads. (500 to 100,000 pound capacities.) Write today for "What You Should Know About Welding Positioners." Address Dept. 305U, Harnischfeger Corp., Milwaukee 46, Wisconsin.

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P&H WELDERS • ELECTRODES • POSITIONERS

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GRADE B-171
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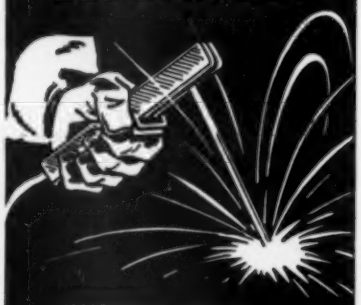
MILD STEEL, LOW HYDROGEN AND HARD-FACING
ELECTRODES



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Arc Welded Projects

46 page booklet, 8½ x 11 in. size. By William A. Sellon, Bemidji State College. Publisher, the James F. Lincoln Arc Welding Foundation, Cleveland 17, Ohio. Price 50¢, postage paid in USA, 75¢ elsewhere.

This booklet is intended as an aid to arc-welding practice in industrial arts shops and as a stimulus to welded-project design. The book contains information for making 25 useful and interesting shop projects, for each of which is given a photograph, a bill of material, construction suggestions and detailed plans. The projects all have been constructed in school shops and were selected for publication on the basis of general interest for the student, welding practice involved, degree of complexity and quality of design.

Projects range from a simple foot scraper to a table saw and cover household, yard, and sport equipment as well as shop tools. A large bibliography lists other projects that have been published in books and periodicals since 1947.

In size and format the booklet is a companion publication to *Arc Welding*, A Basic Manual of Instruction for Learning How to Use Arc Welding.

Technical Translations

The Department of Commerce began publication in January of a periodical planned to serve as a central source of information in the United States on Russian and other technical translations available to science and industry, according to John C. Green, director of Commerce's Office of Technical Services.

The periodical, *Technical Translations*, will be published twice a month by the Office of Technical Services, in cooperation with the Special Libraries Association. It will list and abstract translated material available from U. S. government sources, SLA, cooperating foreign governments, educational institutions and private sources, Mr. Green said.

Survey Results

If you've kept up with your reading, you should now know that five points of especial interest have been developed by the survey requested by a leading advertising agency. Because these 5 points are especially interesting to future advertisers in the Welding Journal, we thought we'd stack them up together to give you a chance to compare them with any magazine in the welding field to determine where you can get the most from the advertising dollar.

1

Read Welding Journal regularly . . . 98%

Proof of complete liaison between the editorial staff and the reader

2

Find Journal contents helpful . . . 98%

Proof that W.J. contents are basic to the whole welding profession

3

Read ads in Journal . . . 87%

Proof that Welding Journal readers are ever-alert for new products

4

Have bought products as result of reading Welding Journal . . . 49% (!)

Proof of effectiveness of Journal for advertising any welding product or service

5

Have investigated new processes on basis of ads in Journal . . . 71%

Proof that W.J. readers are alert, curious, show-me kind of people . . . the kind who are proud of their profession and their contribution to industrial progress. Can you afford to miss this market?

WELDING JOURNAL

"As part of the cooperative arrangement between OTS and the Special Libraries Association," Mr. Green commented, "SLA's *Translation Monthly*, familiar to all who have been working with translations, will be incorporated in *Technical Translations*. Through this OTS-SLA cooperation *Technical Translations* will serve science and industry as a central, time-saving directory to translations completed or in process by many sources."

The Office of Technical Services was authorized by the last Congress to serve as a national "clearinghouse" for technical and scientific translations. For over 13 years, the Office has been collecting, cataloging, reproducing and distributing to science and industry the technical reports growing out of U. S. Government-financed research. These functions were expanded by the Congress to include scientific and technical translations, prepared by agencies of the federal government and other organizations.

Most of the foreign material OTS is collecting from government agencies has not been previously available to the public, and the volume from this source alone is expected to run as high as 10,000 complete translations a year, Mr. Green said. Abstracts of this material began appearing in *Technical Translations* in January.

Technical Translations will be sold by OTS at $12 a year ($4 additional for foreign mailing). Single copy is 60 cents. Orders should be addressed to OTS, U. S. Department of Commerce, Washington 25, D. C.

Plastic Design

Plastic Design in Steel, a design manual published by the American Institute of Steel Construction, Inc., 104 pages illustrated. $4.00 per copy.

The new AISC manual *Plastic Design in Steel* is a reference book for the professional engineer engaged in designing one- and two-story continuous structures. Emphasis is placed on the practical aspects of the subject with a minimum of theory involved. Textbooks and technical reports are available for the student desiring a broader background in the theory.

A section on methods of analysis reviews the equilibrium method for the design of continuous beams and single span, single-story rigid frames as well as the mechanism method for more complicated continuous structures. The reader is then introduced to formulas and charts which permit extremely rapid designs of continuous beams and single and multi-span rigid frames.

Determination of member sizes by one of the methods of analysis does not complete a design; hence several sections in the text are devoted to various details such as column design, connections, lateral bracing and unsymmetrical sections.

Three sections of the book are devoted to the design of continuous beams, single-span frames and multi-span frames. These complete design examples illustrate the use of the various methods of analysis as well as the formulas and charts. Careful attention is paid to the secondary design considerations and the connections. All the designs are in accordance with the AISC Specification for the Design, Fabrication and Erection of Structural Steel for Buildings, and the Supplementary Rules for Plastic Design and Fabrication as approved by the AISC in December 1958.

In addition to the Rules for Plastic Design and Fabrication, the Appendix contains the formulas and charts which the engineer will find quite helpful in designing continuous beams and single and multi-span rigid frames. These charts provide the designer with a more rapid means of applying a design method which in itself is a time saver over the elastic methods of design. An economy table based on the plastic moment strength of rolled sections is also included.

Free Information

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Free Literature

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PAGE 293

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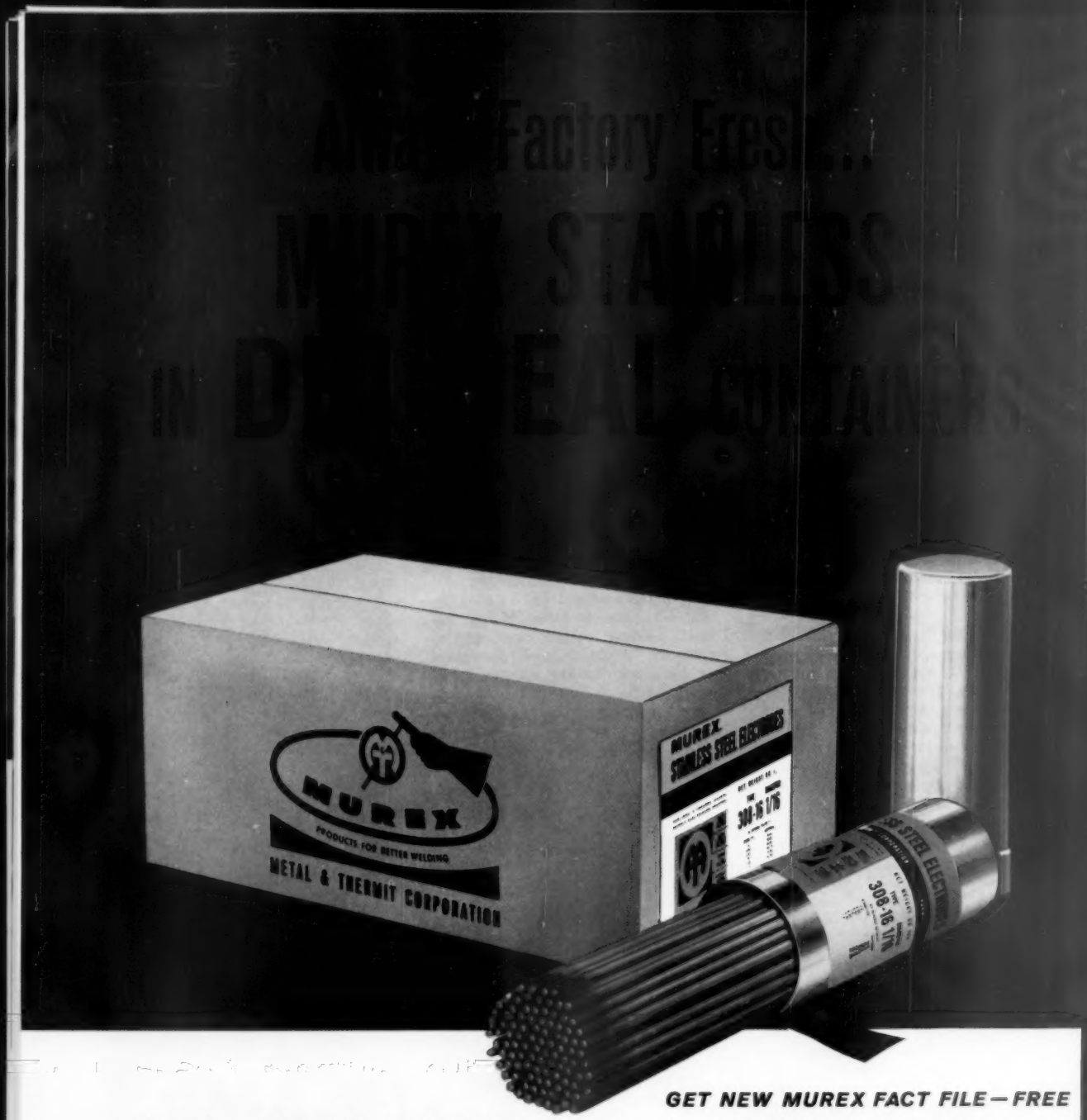

New Murex DRI-SEAL containers guarantee you factory fresh Murex Stainless Electrodes when you first open the package... everytime you use them thereafter.

These extruded aluminum containers are hermetically sealed with a tough, easily removed plastic tape. Open the container, remove the electrodes you need and reseal the container... using the original tape. Complete protection of the unused electrodes is assured.

Murex Stainless Electrodes in reusable DRI-SEAL cans are available for practically every stainless welding application.

GET NEW MUREX FACT FILE—FREE

A revised edition of up-to-date stainless welding facts has just been printed on 3 x 5 cards for easy reference. Send for your complimentary set today.

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For details, circle No. 53 on Reader Information Card

New Products

Plasma Arc Torch

A new method for fabricating shapes and applying coatings that will withstand temperatures above 5000° F has been announced by the Linde Co., Division of Union Carbide Corp., 420 Lexington Ave., New York 17, N. Y.

The process, which reportedly harnesses the highest controlled temperatures ever used in industry—up to 30,000° F—makes possible the fast and accurate mass production of ultra-hard materials that have been virtually unworkable by any conventional means in the past.

The key to the method is the Linde-patented "plasma arc torch," a small device less than two inches in diameter that can melt the toughest materials known to man without being itself consumed by the intense heat it generates.

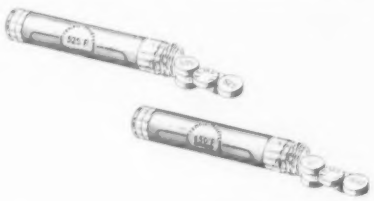
In addition to experimental rocket and missile parts of pure tungsten or tungsten-coated graphite, the new torch has already been used to produce high-density tungsten crucibles for metallurgical purposes, special parts for nuclear work, sensitive electrical contacts, and electronic components and X-ray targets of superior density.

Although a primitive plasma device was first built in Europe 35 years ago, the modern plasma arc did not come until 1955 when Linde introduced the Heliarc plasma jet for cutting aluminum. This was the first commercial process ever to use the power of plasma.

For more details, circle No. 34 on Reader Information Card.

Temperature Indicators

The Tempil° Corp., 132 West 22nd St., New York 11, N. Y., announces that newly developed Tempil° pellets for 525 and 650° F are now available. These temperature ratings were until now the only gaps in



their standard series of Tempil° pellets covering the range from 100 to 2700° F in 90 systematically spaced intervals.

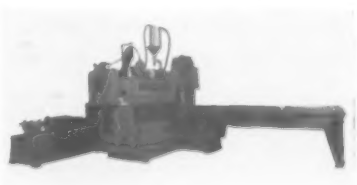
525° F falls in the tool steel tempering range and in the thermosetting level of some of the new epoxy resins. 650° F is also significant in the tempering of tool steels as well as in the heat-treating of aluminum alloys and other nonferrous metals.

The company states that samples of Tempil° pellets in the above mentioned or other available temperature ratings will be sent to readers who request them.

For details, circle No. 36 on Reader Information Card.

Strip-Splicing Machine

The availability of a new strip-splicing machine has been announced by Berkeley-Davis Inc., 1021 Bahls St., Danville, Ill. The machine is designed for use in a continuous tube mill installation and it splices coil stock up to 14 in. in width and $^1/_2$ in. in thickness so that the mill can be run continuously. The machine consists of an entrance table, a double down cut shear, a welding station, and a broaching station.



A set of pinch rolls on an exit table helps control the ends of the skelp.

The welding process is submerged arc, with a Westinghouse head and power source. The weld is made in one pass and on the material now being welded, which is $^5/_{16}$ in. in thickness, the welded area is not noticeable in the finished tube.

The broaching mechanism broaches both top and bottom of the weld bead so that the skelp can go through the succeeding rolls without shock.

The mill is hydraulic in operation, and a complete cycle is made in approximately a minute, depending upon the length of weld being made.

The shearing station consists of a double down cut shear of the toggle type and it is capable of 200-ton pressure.

The machine weighs 48,000 lb and occupies a total floor area of approximately 400 sq ft.

For more details, circle No. 38 on Reader Information Card.

Machine Safeguard

Hobart Brothers, Co., Troy, Ohio have developed Saf-T-Thaw, a protective device that prevents gasoline-engine-driven arc welding machines from burning out because of heavy overloads for too long a period of time.

Gasoline - engine - driven units, rated as low as 250 amp, can be used

safely with Saf-T-Thaw. It is connected in the welding-machine circuit and can be located at the welding machine or at a remote point in the circuit. Its meter shows the current passing through the cables and a standard lag fuse protects the unit against overload.

For details, circle No. 40 on Reader Information Card.

PARTNER IN WELDING PROGRESS SINCE 1904
For details, circle No. 53 on Reader Information Card

Air Gun

The Marindus Co., 51 Pine St., New York 5, N. Y., is marketing a unique, new cleaning and descaling gun.

Called the Von Arx air gun, it easily removes flash, slag and small particles of spatter even from the

most difficult and confined places by means of a set of rapidly reciprocating, hardened-steel needles striking the surface being worked.

These cleaning needles are carried in a needle holder which permits independent action, thus the needles conform to the contour of the surface being cleaned so that uneven surfaces can be cleaned effectively.

The Von Arx air gun operates on normal air pressure, not more than 90 psi and consumes a maximum of only 12 cu ft per min.

For details, circle No. 42 on Reader Information Card.

Immersion Pump

Linde Co., Division of Union Carbide Corp., 30 E. 42nd St., New York 17, N. Y., has announced the development of the HP-8 immersion pump. Its ability to deliver liquid nitrogen and oxygen at high pressures make it important to the missile and rocket industry.

This recently developed pump can reportedly deliver 11,000 standard cu ft of nitrogen per hour. It also delivers oxygen at a rate of 13,750 scfh at 10,000 psi.

The HP-8 is a reciprocating, single-action, positive displacement type pump designed for storage tank operation. It is said to be the most compact and lightest pump of its type on the market. Because of its size, it can be immersed in a tank and therefore eliminate the need for a sump. However, this pump can be mounted independently if a sump operation is preferred.

Standard packings have been replaced by a nonmetallic, self-lubricating packing to reduce friction. Field tests have proved this packing to give almost twice the service life between overhauls as other methods. Since the HP-8 is an immersion pump, it is inherently maintained at operating temperatures and does not require costly cool-down periods before pumping ultra-cold fluids.

The drive for the pump is a 15-hp, 440-v, 60-cycle a-c electrical motor. Its speed is 1750 rpm with a 1:8 reduction gear.

For more details, circle No. 44 on Reader Information Card.

Spot Panel Welding Machine

Schott Metal Products Co., 2225 Lee Rd., Akron 6, Ohio, have introduced a small spot panel welding machine which reportedly welds from one side of the work without distortion or backing.

The unit is designed for use with

any a-c or d-c welding machine of at least 125-amp rating. Iron-powder coated welding rods in $^{1}/_{16}$ and $^{5}/_{64}$ in. diam are used in this method.

For more details circle No. 46 on Readers Information Card.

Grinding Wheels

The Thermacote Co., of Pasadena, Calif. announces a complete line of grinding wheels and abrasive products which is offered to welding distributors.

The Thermacote Co. is manufac-

turing these products under the trade name of "Thermo-Cut."

Factory warehouses on these products will be maintained in Pasadena, Calif.; Chicago; and Atglen, Pa.

For details, circle No. 48 on Reader Information Card.

Soldering Outfit

The "Kwik-Kit," a hard and soft soldering outfit for plant and maintenance personnel, is announced by Special Chemicals Corp., Ossining, N. Y.

Designed for the professional maintenance man as well as for service industries, the kit offers all materials for many emergency repair and upkeep jobs. All metals except aluminum, magnesium and titanium may be joined with the silver-brazing alloy and soft solder in the unit. Fluxes for both are in the unbreakable squeeze bottle.

For more details, circle No. 84 on Reader Information Card.

Magnetic-Tracer Welding System

A new magnetic tape tracer welding system that permits the joining of metal parts having untrimmed, out-of-tolerance, straight line or contour weld line edges in a continuous automated welding operation has been developed by Expert Welding Machine Division, Expert Die and Tool Co., 17144 Mt. Elliott Ave., Detroit 12, Mich.

This system controls self-powered welding heads which automatically follow any type welding contour.

For more details, circle No. 50 on Reader Information Card.

Hard-Surfacing Alloy

Crucible Steel Company of America, Pittsburgh, Pa., recently began to market a new hard-surfacing welding alloy, Rexweld 66.

A nonferrous material especially designed for hot-work applications, Rexweld 66 is said to be highly resistant to thermo-shock, impact and compressive loads at high temperatures and will not chip or spall under the most severe service.

It is a cast nickel-chromium-molybdenum-tungsten alloy designed to produce smooth, sound weld deposits by inert-gas tungsten-arc or metal-arc welding.

Coated with a special low-hydrogen coating, Rexweld 66 electrodes allow all-position welding of various tool and die steels without weld-metal cracking or porosity. Its primary application is on drop-hammer forging dies.

For details, circle No. 52 on Reader Information Card.

For details, circle No. 55 on Reader Information Card→

Tempilstik°. . . . temperature indicating crayons

■ TEMPILSTIKS° provide a simple and accurate means of determining preheating and stress relieving temperatures in welding operations. Tempilstiks° are widely used as a standard method of checking temperatures in all heat treating—as well as in hundreds of other heat-dependent processes in industry. Available in 67 different temperature ratings . . . . . $2.00 each.

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Silver-Bearing Alloy

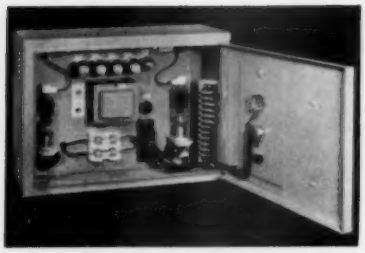
Eutectic Welding Alloys Corp., 40-40 172nd St., Flushing 58, N. Y., has developed a silver-bearing brazing alloy, EutecRod 1801-Super, for joining copper, brass, bronze, steel and stainless steel or dissimilar combinations. The alloy is reported to melt at 1135° F, giving joints of tensile strength up to 80,000 psi. Eutectic officials point out many uses among electronics and electrical equipment manufacturers, toolmakers, gages and meters, and among companies involved in refrigeration, air conditioning, plumbing and heating.

For more details, circle No. 54 on Reader Information Card.

Electronic Welding Control

A new synchronous electronic control designed for use with small bench welding machines has been announced by Robotron Corp., Detroit, Mich.

According to the manufacturer, the new Model 10E49E-A controls the weld current of all types of resistance bench units and is especially suited for resistance welding of small delicate parts such as



dental equipment, electrical parts, jewelry, watches, optical products, radio tubes, etc.

The Model 10E49E-A is available for 115/230 voltage range and is equipped with two plug-in thyratron firing tubes. The thyratron contactor is rated at 12 amp at 50% duty cycle and with a five-second averaging time. External cabinet dimensions of the unit are 22 in. wide, 15 in. high and 10 in. deep.

For details, circle No. 56 on Reader Information Card.

Balanced Wave A-C Welding Machine

Miller Electric Mfg. Co., Inc., Appleton, Wis., has introduced a balanced wave a-c welding machine, Model B-W.

Virtual elimination of the d-c element in power supplied by this model reportedly returns distinctly superior results in hand or automatic fixture tungsten-arc welding.

Positive control of high open circuit of 165 v and arc stability are guaranteed by manufacturer.

Absence of capacitors removes annoyance of arc-outs. Automatic "fail safe" voltage reducer for hand welding and remote amperage control receptacle are standard equipment.

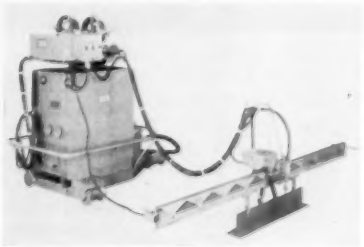
The Miller B-W model welding current ampere ranges are 10–165, 20–260 and 135 to maximum. Rated welding current, 60% duty cycle at 40 v, is 300 amp.

For details, circle No. 58 on Reader Information Card.

Machine Carriage

L and B Welding Equipment, Inc., 2424 6th St., Berkeley, Calif., announce the availability of a twin fillet machine carriage which enables automatic welding of stiffeners, flanges and other structural components from corner to corner.

This heavy duty, aluminum constructed, machine carriage and power supply features dual automatic wire feeds (can be used individually for semiautomatic applications), ensuring maximum production capabilities. The welding machine offers the flexibility and ease of handling required for a



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Mrs. Mildred Fisher of John H. Fisher, General Welding, Wilmington, Delaware finds Manganal Bare easy to use to make the strongest welds faster. Manganal Bare has no coating; leaves no slag; eliminates chipping. Workhardens to 550 Brinell; tensile strength 150,000 psi. It is 100% metal; the most effective and economical electrode to use for reclamation welding. The proof is really in the use of Manganal Bare. Try it and see for yourself.
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For details, circle No. 57 on Reader Information Card

variety of applications in structural, fabrication plants, according to the manufacturer. Units are available for submerged-arc, inert-arc and other consummable welding processes.

For details, circle No. 60 on Reader Information Card.

Portable Liquid-Oxygen Cylinders

The portable liquid-oxygen cylinder—LC-3—has now been made available for sale to manufacturers of liquid oxygen by Linde Co., Division of Union Carbide Corp., 420 Lexington Ave., New York 17, N. Y.

The LC-3 oxygen cylinder is a double-walled, insulated container capable of holding a large volume of oxygen in the liquid state. Since liquid oxygen is nearly 300° F

below zero, the success of the LC-3 is based on the quality of the insulation. It takes several days before enough heat leaks through to boil off enough gas for any to escape through the relief valve.

Here are some of the specifications of the LC-3: height—58 in.; outside diameter—20 in.; capacity (gaseous equivalent)—3000 cu ft; weight, empty—245 lb; weight, full—493 lb; flow rate—300 cfh continuous flow; maximum flow rate—1000 cfh intermittent service; normal delivery pressure—75 lb per sq in.; maximum internal pressure—235 lb per sq in.; safety—meets ICC specifications for interstate transportation.

For details, circle No. 62 on Reader Information Card.

Electrode for Sheet Metal

The Lincoln Electric Co., Cleveland, Ohio has announced Fleetweld 180, a new E-6011 electrode for arc welding sheet metal and for general-maintenance welding with small transformer welding machines.

The manufacturer states that the electrode's ability to operate at

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5 grades to choose from—hardnesses from 160 to 380 Brinell.

Sound, free-flowing deposits join copper-, iron-, and nickel-base metals and alloys; dissimilar metals and alloys. Used extensively to overlay surfaces subject to excessive wear from metal-to-metal contact — or to shock. Resist the corrosive action of salt water, many acids and mild alkalies.

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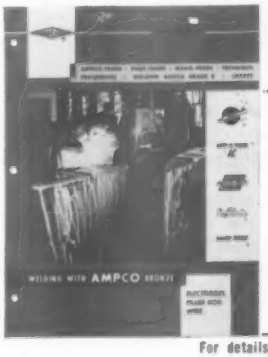

TEAR OUT COUPON — *and mail today for Bulletin W-17 that gives detailed information on Ampco-Trode filler rods and other electrodes.*

W-150

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For details, circle No. 59 on Reader Information Card

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WELDING ENGINEERS
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For details, circle No. 61 on Reader Information Card

currents as low as 50 amp and its light slag make it possible to weld even 0.036-in. (20-gage) material without burn-through. On the other hand, when the current is increased, the arc becomes forceful and deep penetrating so that it is suitable for general repair welding. The electrode is stable on machines with open circuit voltages as low as 45 v. It has a steady arc with industrial a-c welding machines as well as farm or home units.

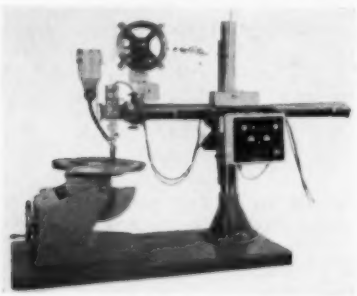
Fleetweld 180 is available in $^3/_{32}$, $^1/_8$ and $^5/_{32}$-in. sizes.

For details, circle No. 64 on Reader Information Card.

Automatic Welding Fixture

A flexible manipulator for automatic welding is being announced by Miami Specialties Co., Troy, Ohio. It consists of a vertical mast and horizontal boom mounted on a base, either pedestal or cylindrical type.

The boom is fabricated of tubular steel with machined, steel guideways



and rack gear. It has infinite travel speeds from 10 to 150 ipm and is powered by a $^1/_4$-hp, 110-v d-c motor. Maximum clearance of the boom is 42 in. and the effective weld length is 42 in. Limit switches protect against overtravel in the forward and reverse directions.

The pedestal base is heavy sheet steel, rigidly reinforced, and measures 36 in. wide, 72 in. long and $4^1/_4$ in. high.

For details, circle No. 66 on Reader Information Card.

Hand Cutting Torches

Air Reduction Sales Co., 150 East 42nd St., New York 17, N. Y., has announced the availability of new injection-type hand-cutting torches designed for use with propane and natural gas.

Known as the Airco 2000 Series, the torches have an "ease-on"

cutting oxygen valve which allows smooth and gradual oxygen flow. This is particularly helpful in hole piercing, rivet washing and stay-bolt cutting.

The torch head is a machined silicon-bronze forging. For rigidity and strength the brass gas tubes are in a triangular arrangement.

For details, circle No. 68 on Reader Information Card.

Nickel-Manganese Electrode

A moderate-cost alloy said to be good for tough, wear-resistant hard surfaces and also for strong, ductile welds has appeared in a low-hydrogen nickel-manganese a-c, d-c electrode announced by All-State Welding Alloys Co., Inc., 249–55 Ferris Ave., White Plains, N. Y. It is recommended for joining and wear-surfacing austenitic-manganese and carbon steels.

As-welded properties include: yield strength, 58,000 psi; tensile strength, 125,000 psi; elongation in 2 in., 50%; hardness as deposited, 18–22 Rockwell C; hardness after work hardening, 44–50 Rockwell C.

Designation for the new electrode is All-State Electrode No. HS-4 ac, dc. Electrode comes in $^1/_8$-, $^5/_{32}$-, $^3/_{16}$- and $^1/_4$-in. core sizes. . .is packed in 10-lb metal containers—6 to a standard carton.

For details, circle No. 70 on Reader Information Card.

Arc Welding Machines

Emerson Electric Manufacturing Co. of St. Louis, Mo. announces a line of a-c welding machines in the 90, 180 and 295 amp sizes for use on farms, in schools, maintenance shops and hobby shops. Also available

is a 200-amp d-c gas-engine-driven portable welder with a-c auxiliary power take-off outlets.

Outstanding features on the more popular 180-amp units include: (*a*) wheels for easy portability; (*b*) NEMA rating, U.L., CSA, and REA approval; (*c*) fan cooling; (*d*) on-off switch; (*e*) 80 OCV to permit use of low-hydrogen and stainless-steel rods; and (*f*) available with or without accessories.

For details, circle No. 72 on Reader Information Card.

Automatic Flash-Welding Machine

A new line of automatic flash-welding machine is now being marketed by Federal Machine and Welder Co., Warren, Ohio.

The 400-kva F5 machine shown is for flash welding hot-rolled steel rings $^3/_8$ in. thick up to 8 in. wide plus flat stock. Air-operated alligator-type clamps provide necessary clamping force to hold the

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that Westinghouse IGNITRONS are built to take it!

The high-peak current conduction capacities of a standard Westinghouse WL 5550 ignitron tube were recently demonstrated in hydrogen fusion experiments at a leading Western university. In this application, ignitrons successfully held off capacitor voltages of 10 kilovolts, and when fired, currents from 30 to 45 thousand amperes were discharged.

Since inventing the original ignitron tube, Westinghouse engineers have introduced a succession of significant improvements—including a water-saving ignitron with a thermostat. Next time you need an ignitron replacement, investigate the dependable, efficient ignitron series offered by the company that originated them . . . Westinghouse!

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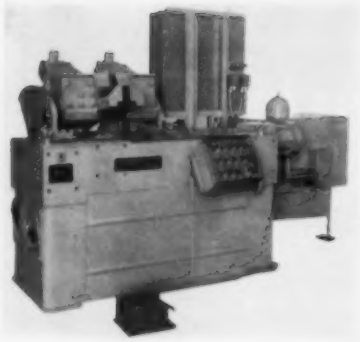
Electronic Tube Division, Elmira, N.Y.

For details, circle No. 63 on Reader Information Card



work. Upset force of approximately 38,000 lb is derived from a double-acting hydraulic cylinder. The hydraulic unit includes an electrical control panel with all necessary relays and timers for controlling the various functions of the hydraulic unit, as well as clamping, flashing, upset, weld-power interruption, unclamping and platen return.

The weld-power interruption, the upset travel, the hold time on the clamp after completion of weld, the hold time after clamp release, the flashing cycle and the flashing curve are all adjustable and calibrated, making duplication of setup very simple.

For details, circle No. 74 on Reader Information Card.

Volatilizing Flux

A new volatilizing flux, which permits brazing in hydrogen or dissociated-ammonia atmospheres such traditionally "hard-to-braze" materials as A 286 and 17-7-PH, is now available from Stainless Processing Division of Wall Colmonoy Corp., 19345 John R St., Detroit 3, Mich.

Named Vapo-Flux, the new material is said to be especially useful

in atmospheres where hydrogen is not suitably reactive. It is available as a powder for mixing with powdered brazing alloy and Nicrobraz cement, or in solution for coating mating surfaces prior to brazing alloy application. When mixed with the brazing alloy, it can be applied with brush, glass dropper, cold spraying or other simple methods.

Vapo-Flux volatilizes during brazing, leaving no residue. It is recommended for use with aircraft assemblies such as honeycomb sandwich structures for high-temperature service.

For details, circle No. 76 on Reader Information Card.

Stainless-Steel Soldering Alloy

A solder-type alloy for stainless steels, StainTin 157-PA, has been introduced by Eutectic Welding Alloys Corp., 40-40 172nd St., Flushing 58, N. Y. According to the manufacturer, this liquid-flux composition is painted on surfaces, then heated until 450° F, the temperature at which it flows and bonds. Free from cadmium and lead, deposits are said to provide up to 15,000 psi in tensile strengths. The composition's main uses are in food contact applications, the sealing of spot-welded and wrapped seams, step soldering of complex assemblies, and filling holes, pits, depressions, tool marks and scribed lines.

For more details, circle No. 78 on Reader Information Card.

Cylinder Insulation

A series of super insulations, reportedly up to 26 times more efficient than standard vacuum insulations, and capable of holding liquid oxygen for indefinite periods, is now in use by Linde Co., Division of Union Carbide Corp., 30 E. 42nd St., New York 17, N. Y.

In a statement made by W. M. Haile, president of Linde, the new insulations constitute a major breakthrough in the field of cryogenic engineering. Using these insulations, Linde is able to build liquid-oxygen storage tanks for missile stands that will hold the volatile liquid for long periods with little loss. Liquid-hydrogen and liquid-helium storage containers that need no liquid nitrogen coolant can also be built.

Fifteen-day pressure rise for the vessel will be below 180 psi. Of course, the super insulations are well suited to such applications, but they are also said to be useful for storing liquid hydrogen, oxygen, and nitrogen. According to Linde, a 26,000-gallon tank can be designed to have an evaporation rate of less than 2.6% of the capacity per year. A similarly designed tank for liquid hydrogen service will lose only 9% per year by evaporation.

For more details, circle No. 80 on Reader Information Card.

Thawing Unit

Porta-Thaw, a small transformer manufactured by Hobart Brothers Co., Troy, Ohio, makes it possible to thaw frozen pipes by using the ordinary domestic a-c electric circuits—110 or 220 v, single phase, 50 or 60 cycles, and can be carried by one man.

It is complete with a 10-ft power cable with plug and receptacle and two 20-ft thawing cables with lugs

and pipe clamps. The case measures only $16^{3}/_{8}$ x $11^{1}/_{2}$ x $10^{3}/_{8}$ in. and the unit weighs 63 lb. Convenient carrying handles are provided.

The transformer is rated at 300 amp, 10 v on 100% duty cycle. Four output terminals of long-life bus-type provide for three thawing steps—high, medium and low. Operating instructions are permanently mounted in plain view, on top of the case.

For details, circle No. 82 on Reader Information Card.

Positioning Clamps

Merrill Brothers, Maspeth, N. Y., have introduced their latest clamp known as the "Third Hand," now in production and available for immediate shipment.

According to the manufacturer, these clamps are so shaped that they may be joined back to back, top to bottom, in parallelled, vertical and horizontal positions at angles of 45, 90 and 180 deg, giving 40 different combinations.

These clamps are made of forged steel, precision machined and copper clad to resist welding splatter, with jaw openings of 2 to 4 in. Each set of clamps comes with a simple locking wrench for fast, easy assembly.

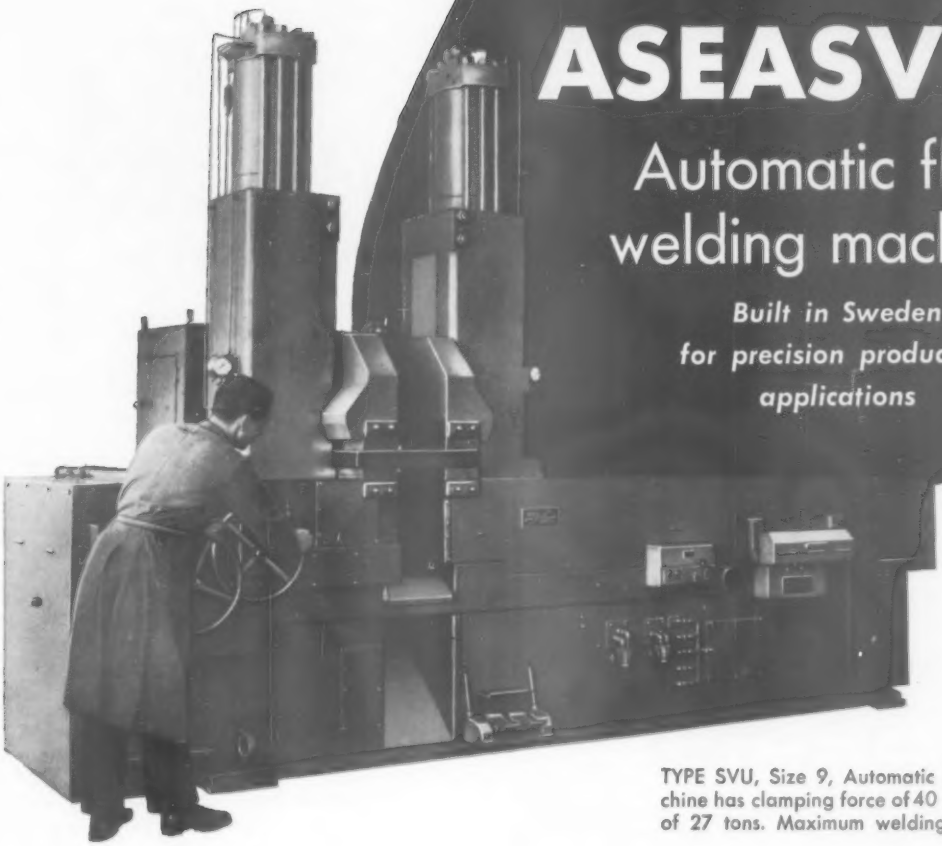
For details, circle No. 98 on Reader Information Card.

Introducing...

ASEASVETS

Automatic flash welding machines

Built in Sweden for precision production applications



TYPE SVU, Size 9, Automatic Flash Welding Machine has clamping force of 40 tons, upsetting force of 27 tons. Maximum welding section 25 sq. in.

Known abroad for their precision performance, ASEASVETS Type SVU Automatic Flash Welding Machines are now available in the United States.

Highly adaptable Type SVU is equipped with hydraulic clamping and motor-operated upsetting and has maximum welding section capacities of up to 40 sq. in.

Automatic control, operated through weld temperature and slide distance, permits predetermination of exact welded length and maintains uniformity of welds when abutting surfaces are uneven.

Machines are available for special purpose applications. They also will be designed to meet your particular needs.

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For details, circle No. 65 on Reader Information Card

65-lb Welding Machine

The Radson Wildcat, a 65-lb welding machine with reportedly more power than units weighing 250 lb and more, as measured by duty cycle and welding heat range, has just been introduced by Radson Engineering Corp., Macon, Ill.

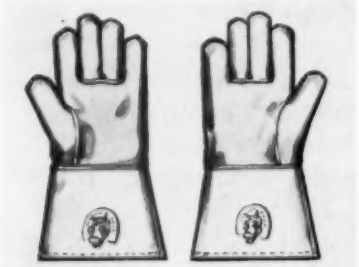
The "Wildcat" employs a full 50% duty cycle through a range of 50 to 200 amp. This is said to be accomplished by a sliding shunt that provides heat control to the exact ampere for any weld job without steps or jumps.

The "Wildcat" is also said to operate on a line draw of less than 30 amp to meet REA specifications. Open circuit voltage between the electrodes is 40 v.

For more details, circle No. 86 on Reader Information Card.

Reversible Welding Glove

A reversible welding glove, "Singer Solo," has been introduced by Singer Glove Mfg. Co., 860 W. Weed St., Chicago 22, Ill. Made from heat-resistant horsehide, the gloves have no exposed seams, thereby permitting interchangeability from one hand to another.

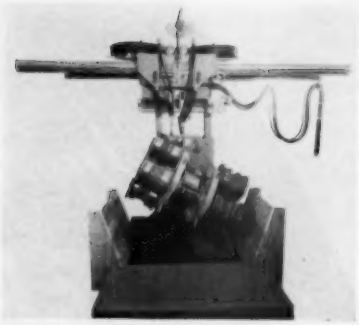


The manufacturer claims that three of these single gloves will outlast two or three pairs of ordinary welder's gloves.

For more details, circle No. 88 on Reader Information Card.

Welding Fixture

L and B Welding Equipment Inc., 2424 Sixth St., Berkeley, Calif., has introduced the Model "Dems" double-ended multiple-spindle welding fixture featuring 8 spindles for



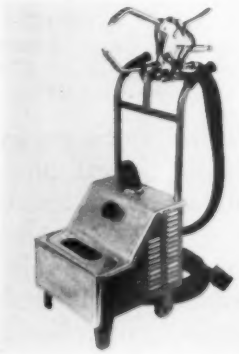
minimizing handling, and increasing the weld cooling cycle when surfacing rollers. The dual welding heads have independent controls for current and positioning. An automatic index moves both heads during welding for finished welds of uniform appearance. A single-console power supply operates on standard 3-phase, 60-cycle, a-c power.

For more details, circle No. 90 on Reader Information Card.

Portable Spot Welding Machine

Peer, Inc., Benton Harbor, Mich., has introduced portable models RP-10 and RP-20 water-cooled gun welders, available in either 10 or 20-kva transformers.

In either model, a built-in electronic timer and magnetic contactor assure highest quality welds with consistency. The hand-operated gun has a toggle lever for high electrode pressure.



The entire unit is mounted on a cart and a 25-ft long heavy-duty power cord is included. A rack mounted on the cart handle supports the gun when not in use.

The 10-kva unit will reportedly weld two pieces of mild steel up to $^1/_8$ in. combined thickness. The 20-kva unit will weld two pieces of mild steel up to $^3/_{16}$ in. combined thickness.

For more details, circle No. 92 on Reader Information Card.

Portable Welding Gun

Research, Inc., 115 N. Buchanan, Hopkins, Minn., have developed Model 4032 portable welding gun for use in the spot welding of thermocouple junctions and similar light assemblies. A longer 200-ft cable

connects this portable equipment to a control console which contains the two-channel weld sequence circuit and a pneumatic system for controlling the weld and forge pressures applied by the gun. Ignitron power-control circuits are employed for weld-current control.

For more details, circle No. 94 on Reader Information Card.

Soldering and Brazing Device

Auto-Test, Inc., 600 S. Michigan Ave., Chicago 5, Ill., has developed a soldering and brazing device called the "Thermo-Weld." Basically the unit consists of a cabinet, 73$^1/_2$-in. 3-conductor cable, a foot pedal, 72-in. ground cable and a

carbon electrode unit with 70-in. cable. One of the features of the product is its capacity to produce instant heating.

For more details, circle No. 96 on Reader Information Card.

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Colmonoy Castings INCREASE Chuck Jaw Life

Castings made of Colmonoy hard-facing alloys are being built into many products at points of extreme wear. They prolong the life of such products many times over.

The chuck jaws shown above are designed using castings of Colmonoy No. 5, silver brazed in place. The benefits: ten weeks of service instead of three, and then easy replacement of the worn insert instead of rebuilding the jaw itself.

Investigate Colmonoy castings. Provide your products (and production equipment) with two, three, or even thirty times longer life, and at modest cost.

Submit part drawings and a description of the wear encountered for a specific recommendation. Request Hard-Facing Manual No. 79.

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For details, circle No. 67 on Reader Information Card

Opinions vary on the preferred finish but–

most welders agree on the preferred electrode

WHETHER your personal choice is in the cleaned finish or the ground finish, Sylvania makes it available to you through your favorite welding supply distributor.

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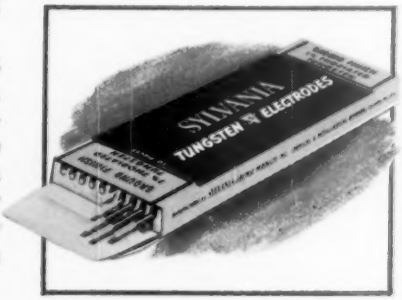

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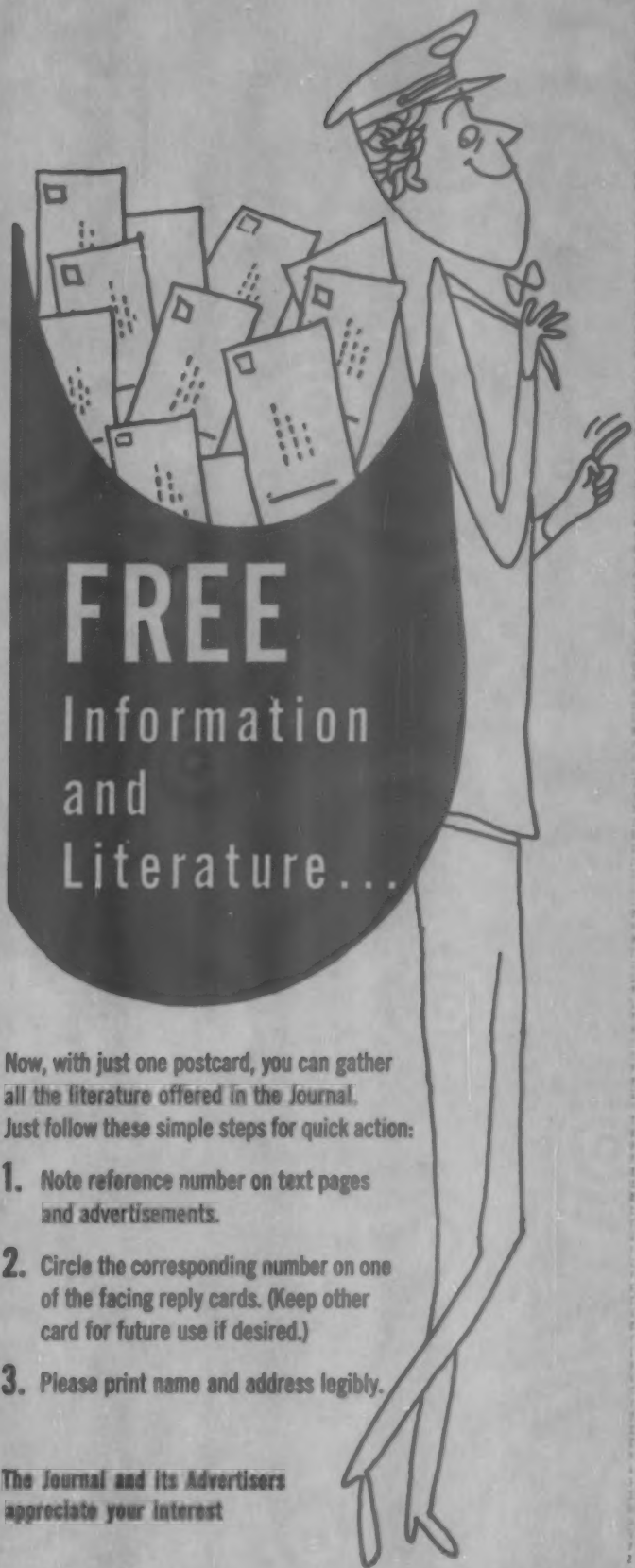

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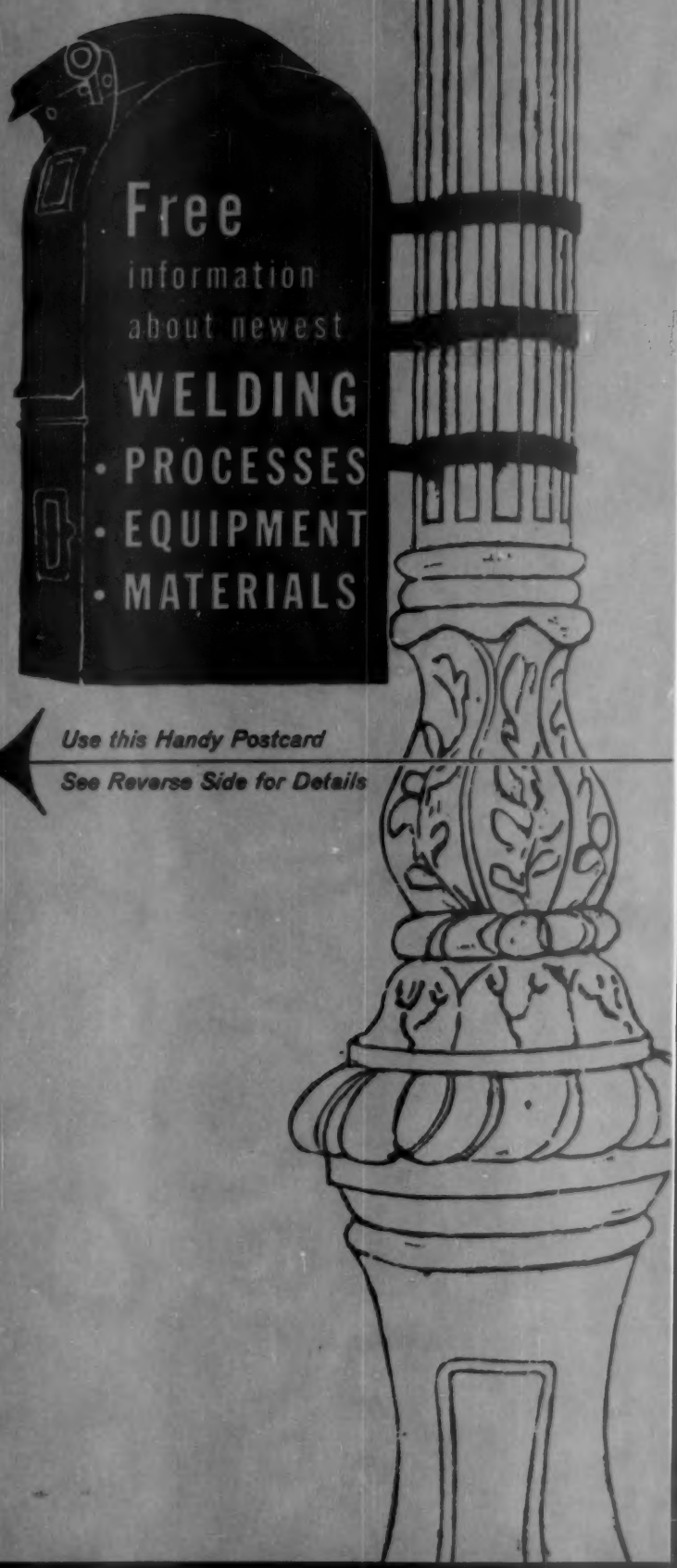

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17	42	67	92	117	142
18	43	68	93	118	143
19	44	69	94	119	144
20	45	70	95	120	145
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SUPPLEMENT TO THE WELDING JOURNAL, MARCH 1959

Welded Cantilever Wedge Beams

Investigation results in formulation of criteria predicting the load-carrying capacity of steel cantilever beams having tapered flanges and webs

BY W. J. KREFELD, D. J. BUTLER AND G. B. ANDERSON

SYNOPSIS. The objective of this investigation was the formulation of criteria predicting the load-carrying capacity of steel cantilever beams having tapered flanges and webs, called "wedge beams." The problem reduces essentially to the experimental determination of critical stresses at which such beams buckle elastically. Tests were conducted on beams having both I and channel sections, with various dimensions, span lengths and degrees of taper.

Extensive load tests were also conducted on straight untapered beams. These tests indicate that a simple relationship exists between the critical buckling stress and the Ld/bt ratio, although these stresses are higher than for corresponding simple beams.

The wedge beams developed stresses at the support when buckling occurred which varied from approximately 50 to 100% of the stresses producing buckling in straight untapered beams having the same section at the support and under the same loading conditions. This reduction is conceived as depending on two opposing factors. One is the higher average flange stresses in the wedge beam for a given loading due to variation of the section modulus along its length. The average flange stress increases with increasing taper and is related to z_0/z_1, the ratio of the section moduli at the fixed and free ends, which can also be expressed as a function of the flange and web tapers. The other factor affecting wedge-beam behavior is the modified torsional or buckling resistance which is assumed to depend on the variation of d/bt along the beam. This variation can be expressed in terms of the ratio of the d/bt parameters at the fixed and free ends of the beam, $(b_0/b_1)(d_1/d_0)$, which also is a function of the tapers. Load reduction factors for wedge beams compared to straight beams have been expressed as relatively simple functions of z_0/z_1 and $(b_0/b_1)(d_1/d_1)$ or the tapers, consistent with the test data. These reduction factors provide criteria for designing wedge beams and establish a basis for economic comparisons.

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Investigation jointly sponsored by the Department of the Navy, Contract Noy-77738 and Welding Research Council.

Paper to be presented at the AWS 40th Annual Meeting in Chicago, Illinois, April 6-10, 1959.

Introduction

The design of cantilever beams is ordinarily based on limiting shear and bending stresses at the support section. Except for light junior sections, the load capacity of standard rolled beams with normal span lengths is determined by yielding at the support, even without the usual precautions against buckling afforded by intermediate bracing and the stiffening effect of purlin framing. However, deep beams with narrow flanges may fail by elastic buckling unless suitable bracing is provided. Although considerable published data on simply supported beams are available, little experimental work has been done on the elastic buckling of cantilevers.

When the load on cantilever beams is limited by yielding at the support, it is apparent that some saving of material can be made by tapering the web depth and flange width, thus providing sections more nearly in accordance with the bending-moment requirements. Such beams with web and flange tapers are referred to as "wedge beams."

This investigation was proposed by the Navy Department because of the lack of design criteria for wedge beams which have been found desirable in certain types of construction. The test program was intended to determine the elastic behavior of cantilever beams and to develop criteria for load capacity which would provide a design procedure and establish a basis for making economic comparisons of wedge beams with alternate straight-beam designs.

Wedge beams can be fabricated by reassembling split rolled sections or by building up sections of any size and shape by welding flat plates cut to trapezoidal form. If the web of an I or channel section having the desired span length is cut diagonally and the separated parts are reversed, the depth will be increased at one end and decreased at the other. Split rolled beams provide constant flange

width and tapered depth. In the case of channels, the rolled sections must be split in pairs to provide companion pieces to form a channel section when reassembled. The fabrication consists of a web weld at midheight of the tapered section. Due to the relief of rolling stresses some warpage of the separated segments may result, particularly in channel sections and beams with narrow flanges, necessitating straightening before welding. The built-up sections assembled from plates cut to provide the desired taper require flange-to-web welds. The form of tapered I and channel beams is shown in Fig. 1.

The initial test program included cantilever beams having various dimensions at the support and end sections. These specimens represented a range of tapers for various I and channel sections and included dimensions previously specified in some Navy Department designs. These specimens were tested with multiple concentrated loads and lateral bracing either at the end only or at each load point. This series of tests was discontinued when it was apparent that beams of these dimensions were not susceptible to failure by elastic buckling and thus provided no information on this phenomenon.

A revised series of tests was made on specimens with narrower and thinner flanges, more likely to fail by elastic buckling. Both yielding and buckling failures were produced which served as a guide to further investigation.

The elastic-buckling resistance determined by these preliminary tests with specimens of selected dimensions was higher than anticipated. It was evident that elastic buckling rather than failure by yielding would be critical only for beams having considerably longer spans than the 16 ft provided by the test rig, narrower and thinner flange sections or higher yield-point steel which would delay failure by yielding.

While the results of the preliminary tests are recorded, the more significant data were obtained from tests on rolled untapered Junior I and channel sections made of material with tension yield point of 43,000 psi, and both untapered and tapered built-up sections made of T-1 alloy steel having a yield point of 100,000 psi. These tests were made with single end loads and with equally spaced four point loading. In order to limit the variables, a single end brace of the top (tension) flange was provided in all cases. A single end load represents the more severe loading condition as indicated by the flange stress distribution in a straight

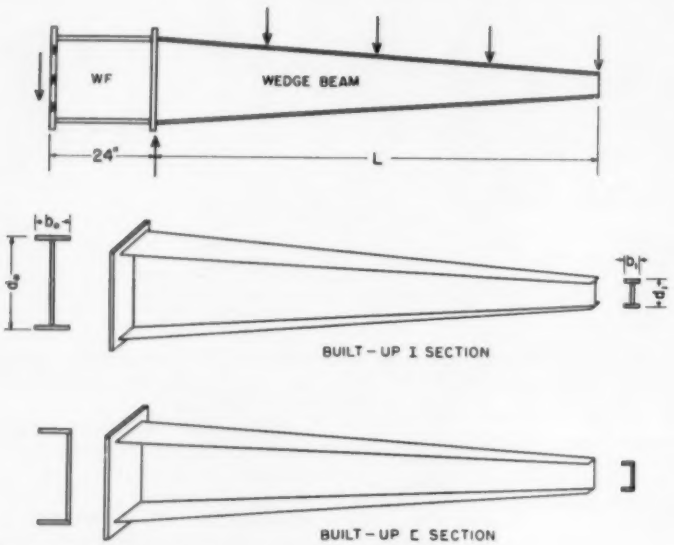

Fig. 1—Wedge-beam specimens. Variable spans and tapers. Flange taper = $T_F = b_1/b_0$; web taper = $T_W = d_1/d_0$.

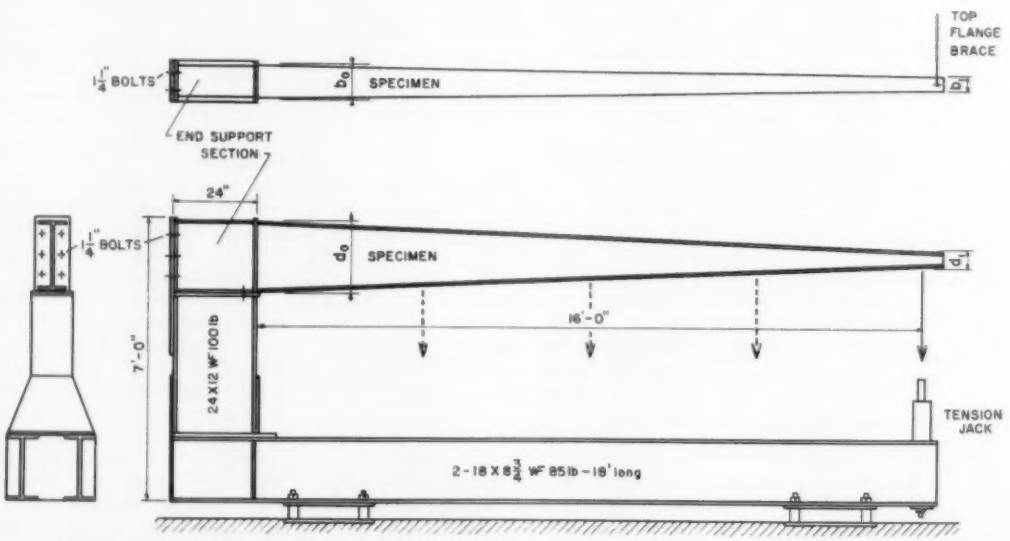

Fig. 2—Testing assembly

Table 1—Summary of Test Results—Original Beam Program

Beam	Section	No. of loads	Bracing	Span length, ft	Depth, in. — Support d_o	Depth, in. — End d_i	Flange width, in. — Support b_o	Flange width, in. — End b_i	Thickness, in. — Flange	Thickness, in. — Web	Tapers — Web $T_w = d_i/d_o$	Tapers — Flange $T_F = b_i/b_o$	z_o/z_i	$\frac{Ld^*}{bt}$	Buckling load per load point, lb	Nominal max stress at support, psi, $= \frac{M_{max}}{z_o}$	Yield point of flange material, psi
13	Built-up [	2	Each load	6	12	4	2.5	1.25	3/8	3/16	0.333	0.500	3.83	912	7550	40,600	38,200
13-A	Built-up [	2	End only	6	12	4	2.5	1.25	3/8	3/16	0.333	0.500	3.83	919	7330	39,400	38,200
14	Built-up [	3	Each load	8	12	4	2.5	1.25	3/8	3/16	0.333	0.500	7.88	1303	3300	34,300	33,000
14-A	Built-up [	3	End only	8	12	4	2.5	1.25	3/8	3/16	0.333	0.500	7.88	1293	4000	42,400	33,000
16	Built-up [	3	Each load	10	13	3	3.0	1.5	3/8	1/4	0.230	0.500	13.4	1377	4970	47,100	32,600
16-A	Built-up [	3	End only	10	13	3	3.0	1.5	3/8	1/4	0.230	0.500	13.4	1374	3800	34,900	38,500
18	Built-up [	3	Each load	12	20	4	4.0	2.0	1/2	1/4	0.200	0.500	15.6	1447	7720	32,200	42,100
18-1	Built-up [	3	Each load	12	20	4	4.0	2.0	1/2	1/4	0.200	0.500	15.6	1398	7750	31,400	35,600
18-A	Built-up [	3	End only†	12	20	4	4.0	2.0	1/2	1/4	0.200	0.500	15.6	1449	8050	33,500	40,600
18-A-1	Built-up [	3	End only	12	20	4	4.0	2.0	1/2	1/4	0.200	0.500	15.6	1397	7710	31,400	35,600
22	Built-up I	3	Each load	12	13	3	5.5	2.5	3/8	1/4	0.230	0.454	13.35	899	6320	46,000	33,700
22-A	Built-up I	3	End only	12	13	3	5.5	2.5	3/8	1/4	0.230	0.454	13.35	900	4910	33,900	‡
24	Built-up I	4	Each load	16	20	4	9.0	4.0	3/8	1/4	0.200	0.444	15.0	1143	7660	36,500	32,600
24-A	Built-up I	4	End only	16	20	4	9.0	4.0	3/8	1/4	0.200	0.444	15.0	1129	7280	34,900	32,600
25	Built-up I	4	Each load	16	20	4	6.0	3.0	5/16	3/16	0.200	0.500	13.65	2033	3340	26,800	29,700
25-A	Built-up I	4	End only	16	20	4	6.0	3.0	5/16	3/16	0.200	0.500	13.65	2019	2800	22,500	29,700

* Based on actual measured dimensions.

† Specimen 18-A was fabricated with pronounced kink at mid-length of compression flange.

‡ No test coupon provided for beam 22-A.

beam which reflects the shape of the bending-moment diagram. The omission of intermediate lateral bracing also is an extreme condition since purlin framing or other lateral bracing, normally used, increases the torsional rigidity of the member. It should also be noted that the bracing used in these tests was applied to the top (tension) flange which is the more likely location in structural applications but its effectiveness in providing lateral support for the compression flange depends on the rigidity of the section.

Economical design of a wedge-beam cantilever is essentially a specification of dimensions which will utilize the full yield-point stress of the material without limitation due to premature elastic buckling. Empirical criteria for predicting the elastic-buckling stress at the support for straight untapered beams and load-reduction factors for wedge beams have been derived from the test data, and apply to these particular loading conditions.

Test Specimens

In order to support the beams as cantilevers, one end was welded to a plate which in turn was welded to the end of a 24-in. length of rolled WF section forming a supporting fixture. A similiar face plate was welded to the other end of the stub beam to provide hold-down bolting to the testing rig. The size of this stub beam varied to provide depth and width corresponding to the end section of the specimen proper and to provide the estimated flexural resistance required. The method of supporting the cantilever specimen is shown in Figs. 1 and 2.

Series I: The beam specimens in this original series of tests were built up from plating cut before welding to provide both web and flange taper. Both I and channel sections were included. The depth varied from 20 to 12 in. at the support, reduced to 4 in. (or 3 in.) at the free end. The flange widths also varied from 9 in. reduced to 4 in. for the larger specimens, and from 2.5 in. reduced to 1.25 for the smallest specimens. The spans varied from 6 to 16 ft. These and other dimensions are recorded in Table 1.

The test program as originally formulated also included beams with similar dimensions fabricated by splitting standard rolled sections. However, this series was discontinued when the test results indicated that beams of these dimensions would develop the yield-strength capacity and were not susceptible to elastic buckling.

Table 2—Summary of Test Results—Revised Wedge-Beam Program

Beam	Secton	No. of loads	Bracing	Span length, ft	Depth, in. Support d_o	Depth, in. End d_1	Flange width, in. Support b_o	Flange width, in. End b_1	Thickness, in. Flange	Thickness, in. Web	Tapers Web $T_w = d_1/d_o$	Tapers Flange $T_F = b_1/b_o$	z_o/z_1	Ld^*/bt	Buckling load per load point, lb	Nominal max stress at support, psi $= \frac{M_{max}}{z_o}$	Yield point of flange material, psi
26	6 [8.2	1	No brace	10	6	6	2.0	2.0	5/16	5/16	1.0	1.0	1	1117	1200	32,400	39,200
29	2½ x 6 [	1	End brace	8	6	6	2.25	2.25	1/4	5/16	1.0	1.0	1	1077	1580	40,300	38,600
27	8 I 18.4	1	End brace	12	8	8	4.0	4.0	7/16	5/16	1.0	1.0	1	703	4210	42,700	38,000
28	10 WF 21	1	End brace	16	10	10	5.75	5.75	5/16	1/4	1.0	1.0	1	947	4100	36,600	35,700
30	4 x 8 I	1	End brace	12	8	8	4.0	4.0	5/16	1/4	1.0	1.0	1	914	2630	33,800	36,300
31	6½ x 12 I	4	End brace	16	12	12	6.5	6.5	5/16	1/4	1.0	1.0	1	1150	2490	43,800	36,800
8rA	6 I 12.5	1	End brace	12	10	2	3.375	3.375	3/8	1/4	0.200	1.0	8.46	1154	2780	28,100	38,520
10rA	8 I 18.4	1	End brace	14	13	3	4.0	4.0	7/16	5/16	0.230	1.0	6.77	1267	3900	24,000	35,500
12rA	10 WF 21	1	End brace	16	16	4	5.75	5.75	5/16	1/4	0.250	1.0	5.61	1655	6100	31,400	35,550
20rA	Built-up I	1	End brace	10	12	4	5.0	2.0	5/16	1/4	0.333	0.400	8.98	945	4580	24,400	34,850
22rA	Built-up I	1	End brace	12	13	3	5.5	2.5	5/16	1/4	0.230	0.454	13.18	1081	5580	31,650	34,850
24rA	Built-up I	1	End brace	16	20	4	9.0	4.0	5/16	1/4	0.200	0.444	15.0	1371	9650	27,250	36,800
8r	6 I 12.5	1	No brace	12	10	2	3.375	3.375	3/8	1/4	0.200	1.0	8.46	1153	2260	22,900	38,320
10r	8 I 18.4	1	No brace	14	13	3	4.0	4.0	7/16	5/16	0.230	1.0	6.77	1263	3330	20,500	37,100
22r	Built-up I	1	No brace	12	13	3	5.5	2.5	5/16	1/4	0.230	0.454	13.18	1082	3880	20,100	34,850
12rB	10 WF 21	4	End brace	16	16	4	5.75	5.75	5/16	1/4	0.250	1.0	5.61	1648	2510	32,150	35,400
20rB	Built-up I	4	End brace	10	12	4	5.0	2.0	5/16	1/4	0.333	0.400	8.98	937	2540	33,800	34,850
24rB	Built-up I	4	End brace	16	20	4	9.0	4.0	5/16	1/4	0.200	0.444	15.0	1371	5280	36,800	36,800
2rA	6 [8.2	1	End brace	10	10	2	2.0	2.0	3/8	3/16	0.200	1.0	9.25	1874	1610	22,300	50,900
4rA	8 [11.5	1	End brace	12	13	3	2.25	2.25	3/8	1/4	0.230	1.0	7.37	2118	1930	17,600	36,620
6rA	12 [20.7	1	End brace	16	20	4	3.0	3.0	1/2	5/16	0.200	1.0	9.08	2583	3310	14,600	38,900
14rA	Built-up [	1	End brace	8	9	3	3.0	1.50	1/4	3/16	0.333	0.500	7.63	1102	2580	28,900	38,900
16rA-1	Built-up [	1	End brace	10	13	3	3.0	1.50	1/4	1/4	0.230	0.500	13.4	1947	2550	19,350	38,580
16rA-2	Built-up [	1	End brace	10	13	3	3.0	1.50	1/4	1/4	0.230	0.500	13.4	1936	2580	19,150	38,580
18rA	Built-up [	1	End brace	12	20	4	4.0	2.0	5/16	1/4	0.200	0.500	15.43	1939	5580	18,950	36,930
2r	6 [8.2	1	No brace	10	10	2	2.0	2.25	3/8	3/16	0.200	1.0	9.25	1867	1480	20,500	46,650
4r	8 [11.5	1	No brace	12	13	3	2.25	2.25	3/8	1/4	0.230	1.0	7.37	2160	1730	16,100	37,250
6r	12 [20.7	1	No brace	16	20	4	3.0	3.0	1/2	5/16	0.200	1.0	9.08	2357	3330	13,900	38,900
14r	Built-up [	1	No brace	8	9	3	3.0	1.5	1/4	3/16	0.333	0.500	7.63	1114	2350	26,450	38,900
18rB	Built-up [	4	End brace	12	20	4	4.0	2.0	3/8	1/4	0.200	0.500	15.43	1898	3070	25,030	36,930

* Based on actual measured dimensions.

Series II: This series represented a revised program with beams having depths and web tapers similar to Series I, but with smaller flange widths. This revision was intended to provide specimens more likely to fail by elastic buckling and thus furnish data which would be useful in developing buckling criteria. That the flange width is an important factor determining the elastic-buckling resistance was confirmed by later tests. This test program included straight rolled channels and I beams, and built-up and split tapered beams. The significant dimensions, spans and loading conditions are shown in Table 2. The failures produced were either by yielding at the support or by what appeared to be buckling. In view of later test results it is likely that some of the beams which appeared to fail by buckling in this series were influenced by lack of straightness or eccentricity of the applied load, and the loads recorded are therefore lower than the true elastic-buckling capacity of the specimens.

Series III: This series was conducted on straight, as rolled, Junior I beams and channels. The beams were 6, 8, 10 and 12 in. deep.

Because of the elastic buckling failures produced with the longer spans, it was possible to retest the same specimen with successively shorter spans, thereby obtaining more data without increasing the number of beams. For example, the 12-in. Junior I beam was tested on 16, 14, 12, 10, 8 and 6-ft spans, in that order. This series established consistent data for critical buckling stresses below the yield point of the material.

Series IV: In order to delay

Fig. 3—Articulated loading yoke

failure by yielding at the support, the specimens in this series were fabricated with T-1 alloy steel having a proportional limit of 90,000 psi. All specimens were built up from plating of I section. Both straight, untapered beams and wedge beams with various flange and web tapers were tested. The significant dimensions are shown in Table 4.

Fabrication: The reported shop procedures in the fabrication of the wedge beams are briefly summarized in the Appendix. This shop report and the included comments indicate that some difficulties were encountered in controlling warpage. However, the measurements made on the specimens as received showed a lack of straightness, not greatly in excess of the tolerance specified for rolled beams. More effective control of warpage caused by cutting and

Table 3-A—Summary of Test Results—Junior I-Beam Series

Beam	Section	Max depth, in.	Span length, ft	Flange width, in.	Flange thickness, in.	Web thickness, in.	Buckling load, lb	Max nominal stress, psi $= \frac{M_{max}}{z_s}$	$\frac{Ld^*}{bt}$	Yield point of flange material, psi
Specimens tested with end-concentrated load and end brace										
12 Jr. A_1	12 Jr. 11.8	12	16	3.02	0.216	0.183	1200	19,824	3575	45,600
12 Jr. A_2	12 Jr. 11.8	12	14	3.02	0.216	0.183	1800	26,019	3128	45,600
12 Jr. A_3	12 Jr. 11.8	12	12	3.02	0.216	0.183	2500	30,976	2681	45,600
12 Jr. A_4	12 Jr. 11.8	12	10	3.02	0.216	0.183	3200	33,040	2234	45,600
12 Jr. A_5	12 Jr. 11.8	12	8	3.02	0.216	0.183	4600	37,997	1787	45,600
12 Jr. A_6	12 Jr. 11.8	12	6	3.02	0.216	0.183	7700	47,703	1340	45,600
12 Jr. B_1	12 Jr. 11.8	12	16	3.02	0.216	0.183	1360	22,412	3623	43,820
12 Jr. B_2	12 Jr. 11.8	12	14	3.02	0.216	0.183	1710	24,658	3170	43,820
10 Jr. A_1	10 Jr. 9.0	10	14	2.73	0.210	0.160	1320	27,950	2956	43,500
10 Jr. A_2	10 Jr. 9.0	10	12	2.73	0.210	0.160	1930	35,024	2534	43,500
10 Jr. B_1	10 Jr. 9.0	10	14	2.73	0.210	0.160	1180	26,133	3053	43,570
8 Jr. C	8 Jr. 6.5	8	16	2.29	0.172	0.136	420	18,600	3920	....
8 Jr. A_1	8 Jr. 6.5	8	12	2.28	0.173	0.144	780	25,880	2921	44,670
8 Jr. A_2	8 Jr. 6.5	8	10	2.28	0.173	0.144	1290	35,668	2434	44,670
8 Jr. A_3	8 Jr. 6.5	8	8	2.28	0.173	0.144	1790	39,595	1947	44,670
8 Jr. B_1	8 Jr. 6.5	8	12	2.28	0.173	0.144	800	26,724	2960	45,070
6 Jr. A_1	6 Jr. 4.4	6	10	1.89	0.161	0.119	610	30,789	2397	44,650
6 Jr. A_2	6 Jr. 4.4	6	8	1.89	0.161	0.119	890	35,937	1918	44,650
6 Jr. A_3	6 Jr. 4.4	6	6	1.89	0.161	0.119	1370	41,489	1438	44,650
Specimens tested with quarter-point loads and end brace										
12 Jr. B	12 Jr. 11.8	12	16	3.02	0.213	0.187	920	37,903	3623	43,820
10 Jr. B	10 Jr. 9.0	10	14	2.67	0.208	0.150	700	38,700	3053	43,570
8 Jr. D_1	8 Jr. 6.5	8	16	2.29	0.172	0.136	280	31,000	3920	....
8 Jr. D_2	8 Jr. 6.5	8	13.5	2.29	0.172	0.136	390	36,400	3310	....
8 Jr. B	8 Jr. 6.5	8	12	2.26	0.172	0.144	506	42,425	2960	45,070
6 Jr. B	6 Jr. 4.4	6	10	1.90	0.161	0.119	346	43,400	2394	....

* Based on actual measured dimensions.

Table 3-B—Summary of Test Results—Straight Channel Series

Beam	Section	Max depth, in.	Span length, ft	Flange width, in.	Flange thickness, in.	Web thickness, in.	Buckling load, lb	Max nominal stress, psi $= \frac{M_{max}}{z_s}$	$\frac{Ld^*}{bt}$	Yield point of flange material, psi
Specimens tested with end-concentrated load and end brace										
8 [A-1	8 [11.5	8.06	16	2.22	0.405	0.225	1780	41,000	1720	41,750
8 [A-2	8 [11.5	8.03	16	2.21	0.400	0.214	1710	40,600	1743	42,450
12 Jr. [A-1	12 Jr. [10.6	11.99	16	1.48	0.304	0.195	700	14,750	5120	41,400
12 Jr. [A-2	12 Jr. [10.6	11.99	14	1.48	0.304	0.195	1000	18,400	4480	41,400
12 Jr. [A-3	12 Jr. [10.6	11.99	12	1.48	0.304	0.195	1310	20,700	3840	41,400
12 Jr. [A-4	12 Jr. [10.6	11.99	10	1.48	0.304	0.195	2040	26,900	3200	41,400
12 Jr. [A-5	12 Jr. [10.6	11.99	8	1.48	0.304	0.195	3390	35,700	2560	41,400
12 Jr. [A-6	12 Jr. [10.6	11.99	7	1.48	0.304	0.195	4100	37,750	2240	41,400
12 Jr. [A-7	12 Jr. [10.6	11.99	6	1.48	0.304	0.195	5070	40,000	1920	41,400
12 Jr. [B-1	12 Jr. [10.6	11.97	10	1.48	0.308	0.197	1990	26,000	3150	40,850
12 Jr. [B-2	12 Jr. [10.6	11.97	7	1.48	0.308	0.197	3890	35,500	2205	40,850
Specimens tested with quarter-point loads and end brace										
12 Jr. [C-1	12 Jr. [10.6	11.98	16	1.49	0.304	0.194	465	24,500	5070	42,175
12 Jr. [C-2	12 Jr. [10.6	11.98	14	1.49	0.304	0.194	625	28,800	4440	42,175
12 Jr. [C-3	12 Jr. [10.6	11.98	12	1.49	0.304	0.194	840	33,230	3800	42,175
12 Jr. [C-4	12 Jr. [10.6	11.98	10	1.49	0.304	0.194	1280	42,200	3160	42,175
12 Jr. [D	12 Jr. [10.6	11.99	9	1.48	0.302	0.195	1560	46,200	2910	42,600

* Based on actual measured dimensions.

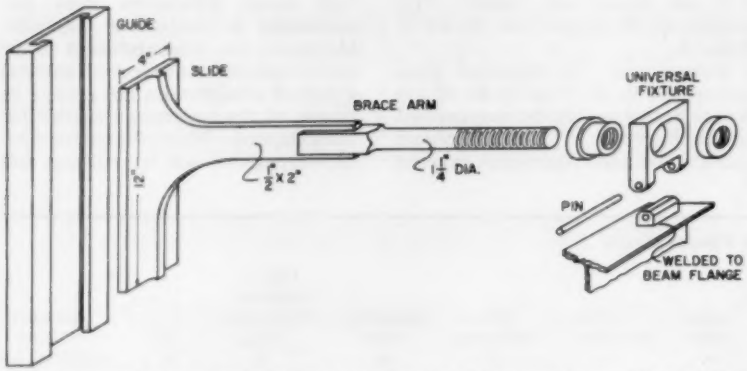

Fig. 4—Exploded view of bracing arm showing guide and universal connection to beam

welding in fabrication would undoubtedly result with more suitable jigs, justified by a larger number of beam units.

As will be noted in the discussion of the test results, even small eccentricities of loading due to lack of straightness can produce considerable decrease in elastic-buckling resistance.

Method of Test

The specimens were supported at one end in a specially constructed "L" shaped frame and loads were applied by hydraulic tension jacks. The general arrangement is shown in Fig. 2. The loads applied by the jacks were measured by tension dynamometers connected to the jack ram. These dynamometers consisted of aluminum-alloy elements provided with averaging and temperature compensating SR-4 gage instrumentation. When multiple loads were applied, the jacks were connected in series to the electrically driven oil pump and the loads were found to be essentially equal for all jacks.

The loads were applied to the top flange of the cantilever. In order to permit unrestrained twist of the section when elastic buckling occurred, the loads were applied through pin connected yokes shown in Fig. 3. In the earlier tests, the top member of the articulated yoke was welded to the top flange of the beam. This required careful placement of the yoke on the centerline of the beam or over the shear center in the case of channel sections. The rigid connection prevented lateral adjustment which was found necessary in later tests to correct for lack of straightness of the beam or misplacement of the loading jacks. The load eccentricity resulting under these conditions accounts for some of the low buckling loads recorded in the earlier tests. The effect of lateral eccentricity of load is most pronounced on deep narrow sections having small torsional rigidity. Similarly a small obliquity of the applied load when unbraced induces large lateral deflections because of the rotation of the neutral axis. In the later tests, on which the conclusions of this investigation are based, the yokes were clamped to the upper flange permitting adjustment. Lateral deflection at low loads was minimized by shifting the yokes to produce essentially vertical deflection. Eccentricity of loading was evidenced by a gradual twist of the section resulting in a lower maximum load than when the section remained vertical and the twist occurred suddenly at elastic buckling.

In the case of the straight channel sections, the loads were first applied through the theoretical shear center and the yokes adjusted to reduce lateral deflection due to crookedness of the beam. The location of the shear center of tapered channels varies along the beam. For channels with web taper only and constant flange width, the distance from the web to the shear center increased toward the small end by amounts depending on the section di-

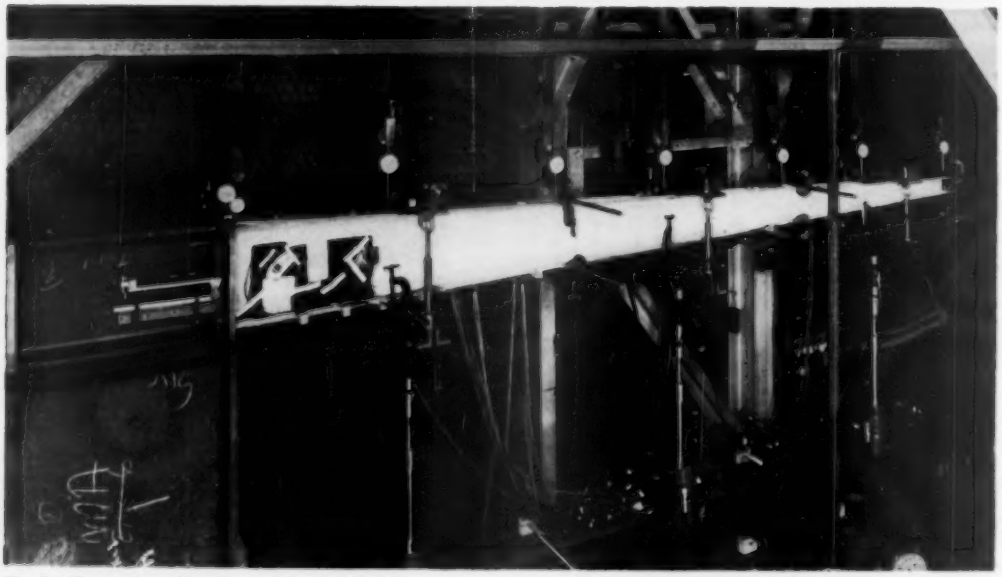

Fig. 5—View of testing rig and instrumentation

mensions. When both the web depth and flange width tapered, the reverse was true, that is, the distance to the shear center decreased to the small end. Because of this variation of the shear center, together with eccentricity due to crookedness, it is not possible to apply loads to tapered channels without some initial twist. In these tests the loading yokes were shifted from the theoretical locations to produce counter balancing twist along the beam with a minimum lateral deflection.

In the original series of tests, bracing was applied to the top flange either at the end only or at each load point. Because of the multiplicity of variables, including sectional dimensions, spans, types of loading and location of braces, the independent influence of these factors could not be evaluated from the number of tests made. The more significant data were obtained from tests made with an end brace only, for both end loading and equally spaced four-point loading. The purpose of the brace was to prevent lateral displacement of the top flange without restricting twist of the section, vertical deflection or longitudinal strain. The bracing fixture used is shown in Fig. 4. The brace consists essentially of a horizontal arm attached at one end to the center of the top flange of the beam and free to move vertically in a guided support at the other end. The attachment to the flange permits rotation of the beam in the longitudinal and lateral planes with a slotted pin connection to permit elongation of the flange. In the absence of twist, no bracing force is developed and the bracing fixture moved downward with the beam

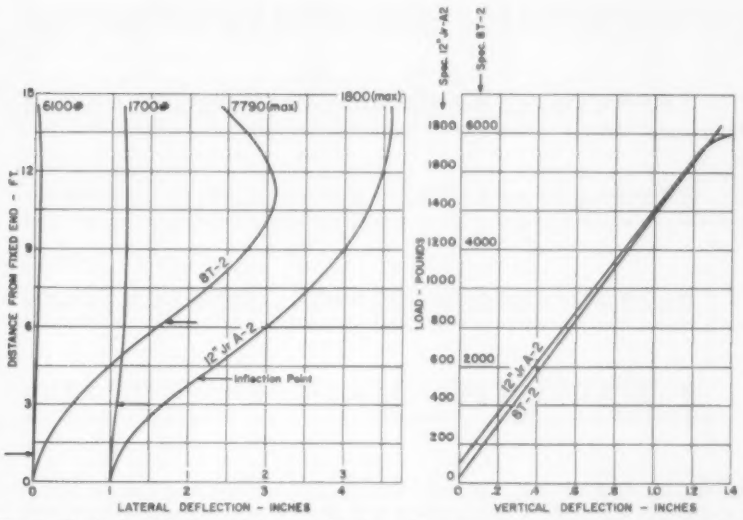

Fig. 6—Typical vertical and lateral deflection of compression flange before and after buckle. End loading. End braced

Fig. 8—View of wedge-channel cantilever loaded at end without brace

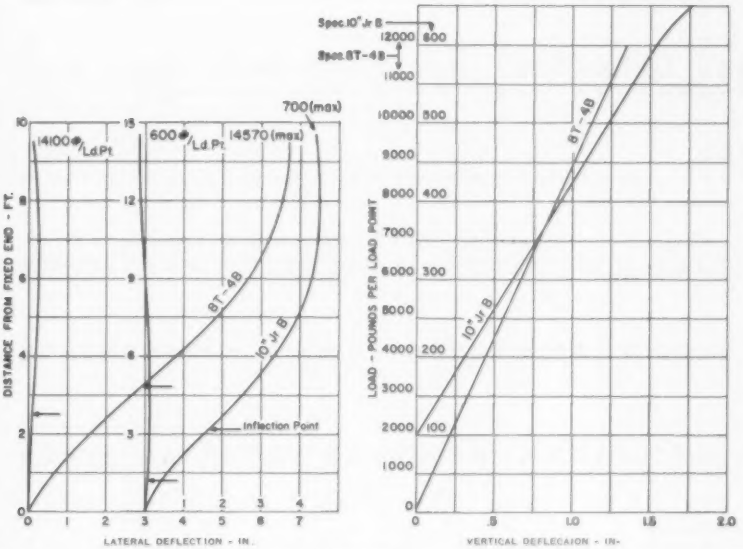

Fig. 7—Typical vertical and lateral deflection of compression flange before and after buckle. 4-point loading. End braced

Fig. 9—View of wedge I cantilever end loaded on short span with end brace

Table 4—Summary of Test Results—High-Yield-Point Steel Series
All Beams Built-up I Sections

Beam	Span length, ft	Depth: Support d_o in.	Depth: End d_i in.	Flange width: Support b_o in.	Flange width: End b_i in.	Thickness: Flange in.	Thickness: Web in.	Taper: Web $T_w = \frac{d_i}{d_o}$	Taper: Flange $T_f = \frac{b_i}{b_o}$	$\frac{z_o}{z_i}$	Taper parameter α	$\frac{Ld^*}{bt}$	Buckling load per load point	Nominal max stress at support $= \frac{M_{max}}{z_o}$	Yield point of flange material, psi	Reduction† factor R
Specimens tested with end-concentrated load and end brace																
T12	12	12	12	3.99	3.99	0.329	0.270	1	1	1	1	1322	9,920	69,600	95,250	1
	10	12	12	3.99	3.99	0.329	0.270	1	1	1	1	1100	14,960	87,500	95,250	1
	15	12	12	3.99	3.99	0.329	0.270	1	1	1	1	1652	6,670	58,600	95,250	1
	9	12	12	3.99	3.99	0.329	0.270	1	1	1	1	993	18,390	96,800	95,250	1
T16	12	16	16	3.76	3.76	0.345	0.265	1	1	1	1	1780	11,600	54,000	125,150	1
	10	16	16	3.76	3.76	0.345	0.265	1	1	1	1	1480	16,670	63,500	125,150	1
	8	16	16	3.76	3.76	0.345	0.265	1	1	1	1	1188	26,080	79,500	125,150	1
1T	16	20	20	4.99	4.99	0.331	0.268	1	1	1	1	2300	9,840	39,400	87,600	1
	14	20	20	4.99	4.99	0.331	0.268	1	1	1	1	2015	14,010	49,000	87,600	1
	12	20	20	4.99	4.99	0.331	0.268	1	1	1	1	1725	19,300	58,000	87,600	1
	10	20	20	4.99	4.99	0.331	0.268	1	1	1	1	1435	26,385	66,000	87,600	1
2T	16	20	16	5	4	0.3125	0.25	0.800	0.800	1.577	1.577	2330	8,210	32,900	93,000	0.818
	14	20	16.5	5	4.125	0.3125	0.25	0.825	0.825	1.485	1.485	2040	11,100	39,000	93,000	0.831
	12	20	17	5	4.25	0.3125	0.25	0.850	0.850	1.39	1.39	1750	16,270	49,000	93,000	0.878
	10	20	17.5	5	4.375	0.3125	0.25	0.875	0.875	1.315	1.315	1457	25,670	64,400	93,000	0.940
	8	20	18	5	4.50	0.3125	0.25	0.900	0.900	1.24	1.24	1170	36,100	72,600	93,000	0.834
3T	16	20	8	5	4	0.3125	0.25	0.400	0.800	4.01	1.43	2325	9,130	36,200	103,150	0.897
	14	20	9.5	5	4.125	0.3125	0.25	0.475	0.825	3.15	1.37	2035	13,240	46,000	103,150	0.979
	12	20	11	5	4.250	0.3125	0.25	0.550	0.850	2.52	1.31	1745	19,470	57,800	103,150	1.031
	10	20	12.5	5	4.375	0.3125	0.25	0.625	0.875	2.08	1.26	1455	28,900	71,600	103,150	1.042
	8	20	14	5	4.50	0.3125	0.25	0.700	0.900	1.75	1.20	1165	40,200	79,800	103,150	0.914
4T	16	20	16	5	3	0.3125	0.25	0.800	0.600	1.90	2.94	2310	7,960	31,600	93,050	0.779
	14	20	16.5	5	3.25	0.3125	0.25	0.825	0.650	1.73	2.48	2020	10,850	37,600	93,050	0.793
	12	20	17	5	3.50	0.3125	0.25	0.850	0.700	1.585	2.12	1735	15,640	46,500	93,050	0.824
	10	20	17.5	5	3.75	0.3125	0.25	0.875	0.750	1.45	1.835	1445	24,300	60,200	93,050	0.872
5T	16	20	10	5	3	0.3125	0.25	0.500	0.600	3.71	2.96	2310	7,390	30,000	86,700	0.739
	14	20	11.25	5	3.25	0.3125	0.25	0.563	0.650	2.98	2.48	2020	10,640	37,850	86,700	0.798
	12	20	12.50	5	3.50	0.3125	0.25	0.625	0.700	2.44	2.13	1730	15,590	47,500	86,700	0.839
	10	20	13.75	5	3.75	0.3125	0.25	0.687	0.750	2.04	1.84	1443	23,530	59,700	86,700	0.864
	8	20	15	5	4	0.3125	0.25	0.750	0.800	1.73	1.61	1156	36,800	74,800	86,700	0.848
6T	16	20	14	5	2	0.3125	0.25	0.700	0.400	2.94	6.81	2320	5,470	22,000	99,300	0.544
	14	20	14.75	5	2.375	0.3125	0.25	0.737	0.475	2.46	4.78	2030	8,420	29,600	99,300	0.627
	12	20	15.50	5	2.75	0.3125	0.25	0.775	0.550	2.10	3.52	1740	13,200	39,800	99,300	0.709
	10	20	16.25	5	3.125	0.3125	0.25	0.813	0.625	1.815	2.69	1450	20,000	50,200	99,300	0.729
	8	20	17	5	3.5	0.3125	0.25	0.850	0.700	1.585	2.13	1160	32,000	64,200	99,300	0.730
7T	16	20	8	5	2	0.3125	0.25	0.400	0.400	6.76	6.76	2320	5,840	23,150	95,750	0.573
	14	20	9.5	5	2.375	0.3125	0.25	0.475	0.475	4.70	4.70	2030	8,960	31,050	95,750	0.658
	12	20	11	5	2.75	0.3125	0.25	0.550	0.550	3.45	3.45	1740	14,100	41,800	95,750	0.744
	10	20	12.5	5	3.125	0.3125	0.25	0.625	0.625	2.64	2.64	1450	21,190	52,500	95,750	0.762
	8	20	14	5	3.5	0.3125	0.25	0.700	0.700	2.09	2.09	1160	33,700	66,700	95,750	0.760
8T	16	20	4	5	2	0.3125	0.25	0.200	0.400	18.15	6.36	2400	5,100	20,650	130,300	0.532
	14	20	6	5	2.375	0.3125	0.25	0.300	0.475	8.96	4.49	2100	7,790	27,600	130,300	0.607
	12	20	8	5	2.75	0.3125	0.25	0.400	0.550	5.39	3.33	1800	12,400	37,600	130,300	0.695
	10	20	10	5	3.125	0.3125	0.25	0.500	0.625	3.61	2.58	1500	19,500	49,300	130,300	0.744

Specimens tested with quarter-point loads and end brace																
T16	16	16	3.76	3.76	0.345	0.265	1	1	1	1	2370	4,760	72,500	125,150	1	
	14	16	3.76	3.76	0.345	0.265	1	1	1	1	2075	6,210	83,000	125,150	1	
	12	16	3.76	3.76	0.345	0.265	1	1	1	1	1780	8,170	93,500	125,150	1	
1T	16	20	4.99	4.99	0.331	0.268	1	1	1	1	2300	7,790	77,900	87,600	1	
	14	20	4.99	4.99	0.331	0.268	1	1	1	1	2010	9,850	86,300	87,600	1	
2T	16	20	16	5	4	0.3125	0.25	0.800	0.800	1.577	1.577	2330	6,000	60,300	93,000	0.830
	14	20	16.5	5	4.125	0.3125	0.25	0.825	0.825	1.485	1.485	2040	8,140	71,500	93,000	0.833
	12	20	17	5	4.25	0.3125	0.25	0.850	0.850	1.39	1.39	1750	11,240	84,600	93,000	0.819
3T	16	20	8	5	4	0.3125	0.25	0.400	0.800	4.01	1.43	2325	7,790	77,200	103,150	1.058
	14	20	9.5	5	4.125	0.3125	0.25	0.475	0.825	3.15	1.37	2035	10,400	90,200	103,150	1.048
4T	16	20	16	5	3	0.3125	0.25	0.800	0.600	1.90	2.94	2310	6,440	63,900	93,050	0.869
	14	20	16.5	5	3.25	0.3125	0.25	0.825	0.650	1.73	2.48	2020	8,780	76,200	93,050	0.876
5T	16	20	10	5	3	0.3125	0.25	0.500	0.600	3.71	2.96	2310	6,040	61,400	86,700	0.836
	14	20	11.25	5	3.25	0.3125	0.25	0.563	0.650	2.98	2.48	2020	7,960	70,800	86,700	0.814
	12	20	12.50	5	3.50	0.3125	0.25	0.625	0.700	2.44	2.13	1730	11,730	89,500	86,700	0.854
6T	16	20	14	5	2	0.3125	0.25	0.700	0.400	2.94	6.81	2320	4,960	49,800	99,300	0.680
	14	20	14.75	5	2.375	0.3125	0.25	0.737	0.475	2.46	4.78	2030	7,960	70,000	99,300	0.811
	12	20	15.50	5	2.75	0.3125	0.25	0.775	0.550	2.10	3.52	1740	11,500	86,600	99,300	0.833
7T	16	20	8	5	2	0.3125	0.25	0.400	0.400	6.76	6.76	2320	4,860	48,100	95,750	0.657
	14	20	9.5	5	2.375	0.3125	0.25	0.475	0.475	4.70	4.70	2030	7,760	67,200	95,750	0.778
	12	20	11	5	2.75	0.3125	0.25	0.550	0.550	3.45	3.45	1740	10,900	81,000	95,750	0.778
8T	16	20	4	5	2	0.3125	0.25	0.200	0.400	18.15	6.36	2400	4,160	42,100	130,300	0.602
	14	20	6	5	2.375	0.3125	0.25	0.300	0.475	8.96	4.49	2100	6,440	57,000	130,300	0.687
	12	20	8	5	2.75	0.3125	0.25	0.400	0.550	5.39	3.33	1800	9,610	73,000	130,300	0.730
	10	20	10	5	3.125	0.3125	0.25	0.500	0.625	3.61	2.58	1500	14,570	92,000	130,300	0.741

* Based on actual measured dimensions.

† Based on buckling stresses for untapered beams as determined from the curves, eqs 2 and 4, Fig. 10.

under its own weight. Friction in the guide was overcome by slight tapping with a hammer and the arm was maintained horizontal, using a level gage. Due to the flexibility of the bracing fixture, its effect on the applied loads was negligible. Tensile or compressive forces were developed in the bracing arm only after the beam buckled. The bracing force to resist lateral deflection at the end could not be large in these beams because of the low flexural resistance about the weak (I_y) axis.

The instrumentation is shown in Fig. 5. The measurements included strains along both flanges by SR-4 gages to verify the theoretical stress distribution along the beam and Whittemore-gage strain measurements on 2-in. gage lengths on both edges of the flanges to detect lateral bending. In the early tests, the progress of twist was indicated by measurements of rotation of both flanges. These rotations were measured by level gages placed on rods clamped to the flanges and projecting laterally. The vertical deflections were measured at intervals along the beam with recording dials. A level gage attached to the beam support provided measurement of the support rotation for correction of the measured vertical deflections. The lateral displacement of the bottom flange was measured with a millimeter scale using fine wires suspended vertically from the bottom flange.

These measurements confirmed the computed elastic deflection curves and stress distribution along the flanges. The later tests included only sufficient flange strain measurements to confirm the nominal flexural stresses in the vicinity of the support, together with vertical and lateral deflections, and edge flange strains to determine the lateral curvature.

Loading was continued until yielding was produced at the support or the beam failed by elastic buckling with a sudden twist of the section. In Series III and IV, where the beams buckled with critical stresses considerably below the yield point of the material, the beams returned to shape after removal of the load and the same beam specimen was retested on shorter span lengths, thus providing additional data without requiring more beam specimens. In some cases, permanent distortion, due to continued twisting after elastic buckling had occurred, was prevented by using stop blocks which limited the lateral deflection of the compression flange to a few inches.

Results of Tests

The significant dimensional data, test loads and computed stresses for all specimens tested are recorded in Tables 1 to 4. The large number of strain and deflection measurements recorded during the tests will not be presented here. Most of these measurements were intended for control and verification purposes. The measured vertical deflections agreed very closely with computed values. Increasing rate of elastic deflection was associated with increasing lateral deflection and the approach of buckling. The lateral curvature of the compression flange as measured by the lateral deflections was verified by strain measurements taken on the edges of the flange which established the point of contraflexure. Typical vertical and lateral deflection curves are shown in Figs. 6 and 7. Lateral-deflection curves of the compression flange are shown for a tapered beam with built-up section and a straight Junior I section for loads just prior to elastic buckling and immediately after buckling. It should be noted that the deflection shown at the end of the cantilever reflects the amount of twist at the end section since the top flange was braced. The beams remained essentially straight until the critical buckling load was reached. The distorted shape after buckling is shown in the photographic views of beams after test. Figure 8 shows a tapered channel of the original series which was loaded with dead weights at the end, without lateral bracing. Figure 9 is a view of a built-up I section, taken from the support end, after loading on a short span.

The beam did not continue to twist after buckling with resultant complete collapse because of the decrease of jack load when sudden deflection occurred. The compression flange bent laterally in a reverse curve. In the case of straight I beams with end loads, the point of contraflexure after buckle was located approximately 0.65L to 0.75L from the free end, while for the straight channels this point was somewhat nearer the support. This point of curvature reversal in the case of tapered beams was further from the support, at distances which varied with the amount of taper. For four-point loading, the curvature reversal occurred nearer the support. The differences in curvature are associated with the relative torsional rigidity of the larger section near the support as compared with the smaller and more flexible sections near the end of the tapered cantilever. The vertical - deflection curves show elastic behavior until buckling occurred. The top flange of the braced beams remained essentially straight, longitudinally, except for a slight lateral bow after buckling of the compression flange due to small forces transferred by the beam web.

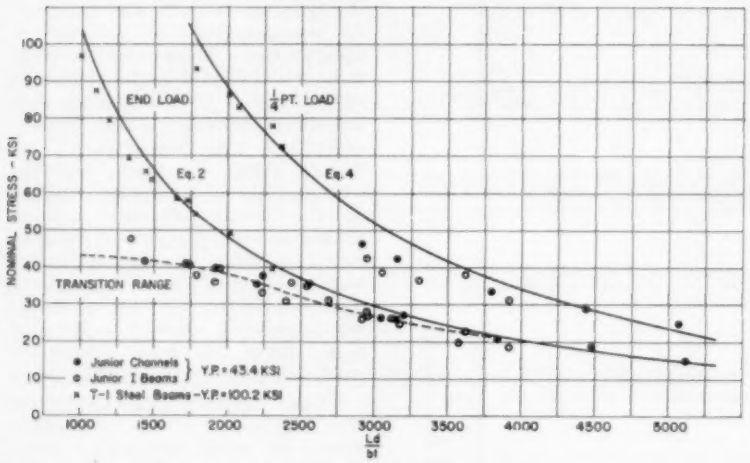

Fig. 10—Buckling stress for untapered cantilever beams

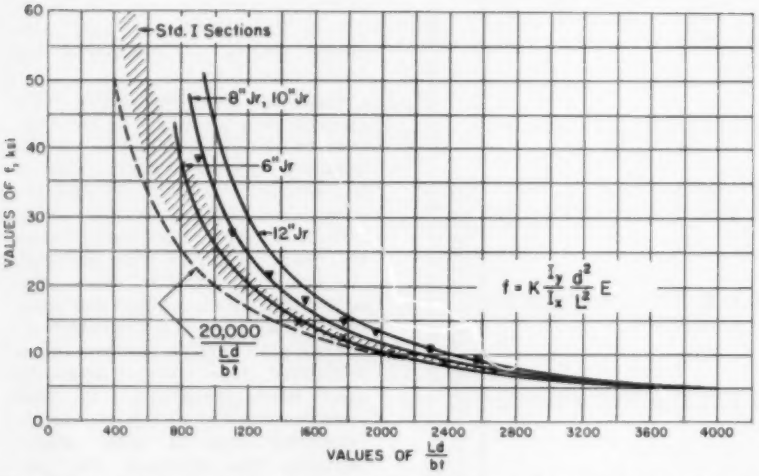

Fig. 11—Simple beam, uniform load on top flange. Curves for Jr. I sections. Plotted points—specimens of series IV. IT = ●, 12T = ▼, 16T = ×

Tests on Straight Beams Without Taper

Series III consisted of tests on 12-, 10-, 8- and 6-in. Junior I sections and 12-in. Junior channels. Series IV also included built-up beams with uniform I section, 20, 16 and 12 in. deep with flanges 5, 4 and $3^3/_4$ in. wide and $^5/_{16}$ in. thick. These beams were tested on spans of 8, 10, 12, 14 and 16 ft except as noted. Because of the low stresses developed in the longer spans when elastic buckling occurred, it was possible to re-test the same specimen on shorter spans until either yielding at the support or distortion due to buckling rendered the specimen unsuitable for further testing. In some tests, permanent distortion was avoided by placing stop blocks a few inches from the edges of the compression flange to limit the amount of twist after buckling occurred. These beams were subjected to single end loads and also equally spaced four-point loads, with end brace in all cases.

The nominal stress at the support, computed by the flexure formula, for loads producing elastic buckling, is plotted against the Ld/bt ratio in Fig. 10. This ratio has been shown to be an approximate measure of the buckling re-

sistance of simply supported beams.[1,2] It is reasonable that this parameter should also serve to predict buckling resistance of cantilevers although the functional relationship will differ depending on supporting conditions and the type of loading.

The test results on Junior channels and Junior I beams are in substantial agreement, with plotted data falling on the same curve. For stresses approaching the yield point of the material, the curves show a transition from elastic buckling to yielding-type failure. This transition might be represented as a parabolic segment of the elastic buckling curve for the lower values of Ld/bt. However, this transition curve will depend upon the slope of the stress-strain curve of the material beyond the proportional limit, which was low in the material tested. The tests on built-up I sections made of T-1 alloy steel permitted extension of the elastic buckling curve to lower values of Ld/bt because of the higher yield point of this material.

The curves shown in Fig. 10 can be expressed by the following approximate equations:

For *end load* and end brace,

$$S_{cr.} = \frac{80{,}000{,}000}{Ld/bt}$$

$$\text{for } 5000 > \frac{Ld}{bt} > 2500 \quad (1)$$

$$S_{cr.} = \frac{110{,}000{,}000}{Ld/bt} - 7000,$$

$$\text{for } 5000 > \frac{Ld}{bt} > 1000 \quad (2)$$

where S_{cr} is the nominal stress at the support when elastic buckling occurs.

For *equally spaced four-point loads*, simulating uniformly distributed loading, and end brace,

$$S_{cr} = \frac{130{,}000{,}000}{Ld/bt}, \text{ for}$$

$$5000 > \frac{Ld}{bt} > 3500 \quad (3)$$

$$S_{cr} = \frac{216{,}000{,}000}{Ld/bt} - 20{,}000,$$

$$\text{for } 5000 > \frac{Ld}{bt} > 2000 \quad (4)$$

Equations 1 and 3, although simpler, become increasingly conservative for high yield point material below the limits of Ld/bt specified. The transition curve shown dotted in Fig. 10 represents the critical stresses for the test material which had a proportional limit of approximately 28,000 psi and is not defined by the above equations. The plotted points for the quarter-point loading, in the vicinity of Ld/bt = 3000, are also low because of the influence of yielding.

It will be noted that the curves, Fig. 10, were drawn favoring the higher test results since they are intended to represent behavior under ideal conditions, when it was observed that the beams buckled with a very sudden twisting of the section. Deviations from ideal conditions, due to crookedness of the specimen or eccentricity of loading, resulted in a more gradual twisting with somewhat lower critical loads. In some cases, it was possible to obtain more consistent results by making slight adjustments in the lateral position of the loading yokes. The problem was complicated by the relatively low torsional rigidity of the test specimens. Lateral displacement of the load point by as little as $^1/_{16}$ in. was sufficient to affect the results considerably and in fact reverse the direction of twist in some cases.

Comments on the Behavior of Straight Cantilever Beams

1. The stress at the support when elastic buckling occurs can be expressed as a function of the Ld/bt ratio as represented by eqs 1 to 4. The buckling stresses for cantilevers are higher than those for simply supported beams having the same Ld/bt ratio.

2. The critical support stress

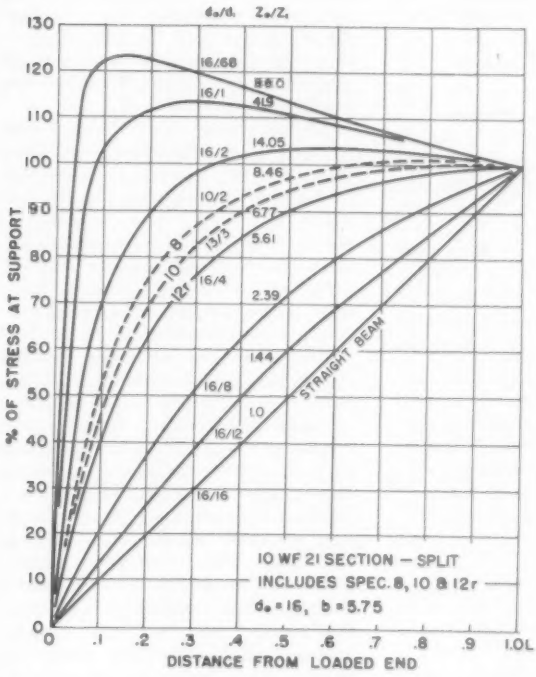

Fig. 12—Flange stress distribution. Constant flange width—variable depth. Single end load

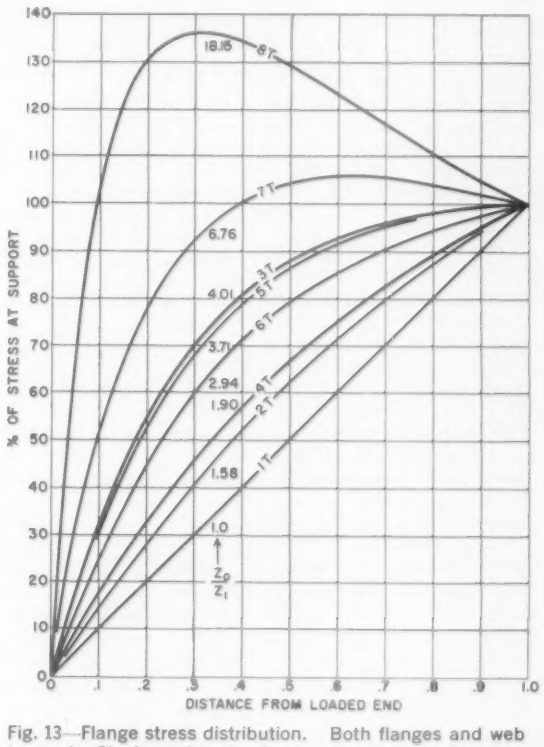

Fig. 13—Flange stress distribution. Both flanges and web tapered. Single end load. For specimen dimensions see Table 4

predicted by eqs 1 and 3 is increasingly conservative for values of Ld/bt below approximately 2500 for end loads or 3500 for uniform loads. The same limitation of a simple function of this form exists for the equation $S = 20{,}000/Ld/bt$ ksi suggested by DeVries for simply supported beams. Figure 11 shows the computed critical stresses for 6-, 8-, 10- and 12-in. Junior I sections and the 20-, 16- and 12-in. deep built-up sections tested in Series III and IV when supported as simple beams. These curves are superimposed on the band of critical stress values for standard rolled sections as computed by DeVries.[1]

Equations 2 and 4 predicting the critical buckling stress for cantilevers with end brace are reasonably consistent with the test data over a wider range of Ld/bt ratios. Similar equations could be applied to simply supported beams.

3. Referring to the steel handbook, it will be noted that the d/bt ratios listed do not exceed 5 and for most sections are considerably less. The Junior and built-up sections tested had d/bt ratios ranging from 10 to 20. The rolled sections included in Series II, with a yield point of the flange material of 36–39,000 psi, failed by yielding. These beams had Ld/bt ratios of 700 to 1100, which is considerably less than the limiting value for which elastic buckling controls failure. According to Fig. 10, this limiting Ld/bt ratio is about 2500 for end loads. Accordingly, ordinary rolled sections with practical spans are not susceptible to elastic buckling under the loading conditions for which these data are applicable. Reduction in strength due to eccentricity or obliquity of loading and crookedness of the beam may be large and allowance should be made for these conditions particularly for light sections.

4. End loading is a more severe loading condition than uniform loading as indicated by the relative bending - moment diagrams. It would be expected that a cantilever without any bracing would have lower capacity. The practical application of such beams is not apparent. An increase of buckling capacity would result from additional intermediate bracing. When loads are applied through purlins attached to the top flange, some increase in torsional rigidity should result by reason of the lateral stiffness of the assembly. These data are limited to beams with bracing at the end only.

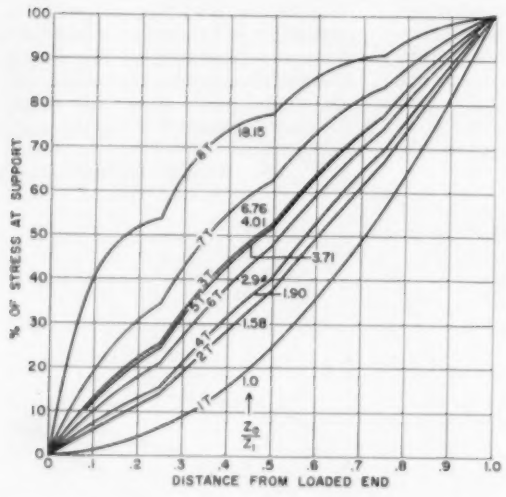

Fig. 14—Flange stress distribution, both flanges and web tapered. Four-point loading. For specimen dimensions see Table 4

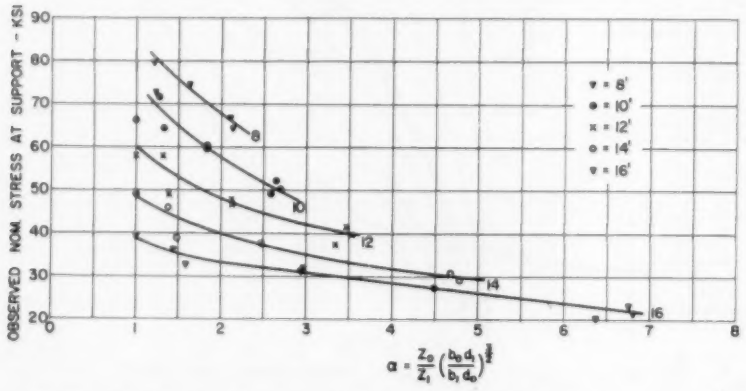

Fig. 15—Dependence of S_{cr} on α and L for wedge beams. End loading— same $\frac{d_o}{b_o t}$

Tests on Wedge Beams

Because of the limited knowledge of the elastic-buckling phenomena in cantilevers and tapered beams in particular, some random testing was unavoidable. The results of tests on the beams selected for Series I and II, while contributing only limited information from which a buckling criterion might be developed, were satisfying in that they established the adequacy of beams having these dimensions, some of which were recommended in previous designs. The significant data are provided by Series IV consisting of beams made of T-1 alloy steel with various flange and web tapers.

Comparing a wedge cantilever beam with a beam of uniform section having the same span and same section at the support, two factors affect the relative load capacities, namely, the average flange stress and its distribution, and the variation of the sectional property d/bt which reflects the buckling resistance.

In the case of a beam with uniform section, the stress along the flange varies according to the change in bending moment, that is, linearly for an end load. The stress in the flange of a wedge beam depends on both the bending moment and the nonlinearly varying section modulus, which depends upon the degree of taper for a given loading.

The influence of taper on the flange stress distribution is shown in Figs. 12, 13 and 14. The stress at any point along the span is shown as a percentage of the stress at the support. Figure 12 indicates the flange stress distribution for beams with constant flange width and variable depth, subjected to end load. Three of these beams with web tapering from 10 to 2 in., 13 to 3 in., and 16 to 4 in. were fabricated by splitting rolled sections diagonally and tested in Series II. The computed values shown were confirmed by strain-

gage measurements. The remaining curves represent beams with the flange dimensions of a 10 WF 21 section, but arbitrarily varying web tapers. The ratio of beam depths and section moduli at the ends are shown on the respective curves. Similar computed stress ratios are shown in Fig. 13 for beams of Series IV having both web and flange taper, loaded with end load. The curves in Fig. 14 are also of the beams in Series IV subjected to equally spaced four-point loading, simulating uniform load.

It will be noted that the flange stress at points within the span increases with increasing taper and that for extreme tapers the flange stress may be greater at points near the end of the cantilever than at the support. The average stress, as measured by the area under the curves, increases with increasing taper. Since the stress at a given point depends on the section modulus determined by the taper, the average flange stress is some function of the relative section moduli at the ends. It would be expected that beams with higher average flange stress would be more susceptible to elastic buckling. In the absence of theoretical analyses, the ratio Z_0/Z_1 is taken as a measure of the average flange stress, in the analysis which follows.

Since the resistance to elastic buckling has been shown to depend upon the dimensional ratio d/bt, it is reasonable to assume that variation of this factor would modify the resistance of the tapered beam. With a decrease of d/bt by tapering the section, the buckling resistance will increase. This increase of torsional rigidity is therefore related to the degree of taper which may be expressed as the ratio of the d/bt factors at the end sections, i.e.: $b_0/b_1/d_1/d_0$.

According to this reasoning, the load producing elastic buckling of a tapered beam as compared with the capacity of a beam with uniform section and same section at the support should depend on two opposing effects, namely, the increase of average flange stress measured by Z_0/Z_1, tending to decrease the critical stress at the support and, the decrease of d/bt which tends to increase the buckling resistance. Accordingly, the reduction in stress at the support of a tapered beam when buckling occurs as compared with the corresponding stress in a beam of uniform section can be expressed by a reduction factor, R, where

$$R = F\left[\left(\frac{z_0}{z_1}\right),\ \left(\frac{b_0}{b_1}\frac{d_1}{d_0}\right)\right]$$

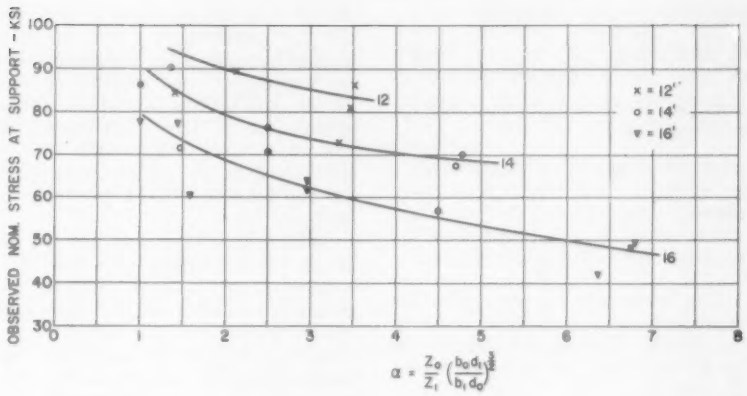

Fig. 16—Dependence of S_{cr} on α and L for wedge beams. 4-point loading — same $\frac{d_o}{b_o t}$

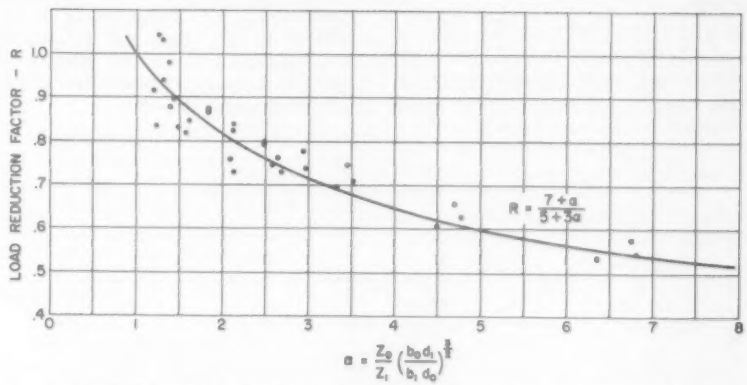

Fig. 17—Load-reduction factors for wedge beams with end-concentrated loads

An empirical equation involving these factors and in agreement with the test data has been developed. This reduction factor permits evaluation of the critical stress at the support producing elastic buckling of a tapered beam when the limiting stress for a beam of uniform section with the same support section is known.

The critical stress producing buckling of a tapered beam with a given span was found to vary with the parameter,

$$\alpha = \frac{z_0}{z_1}\left(\frac{b_0 d_1}{b_1 d_0}\right)^{3/2}$$

Figure 15 shows the dependence of the critical buckling stress in tapered beams on α and L for beams subjected to end load.

Figure 16 shows similar relations for tapered beams with four-point loading. The observed nominal support stresses are somewhat more irregular for the four-point loading because of the greater difficulty in applying the loads without initial twist which caused a decrease in buckling load. These tests, involving high flange stresses were made subsequent to the end-load tests on the same specimen.

These curves present a reasonable confirmation of the hypothesis presented.

Reduction Factors for Wedge Beams

The reduction factor, R, is defined as the ratio of the nominal stress at the support of a wedge beam to that of an untapered beam having the same section at the support, when elastic buckling occurred. These ratios, determined from the observed buckling loads of the wedge beams in Series IV and the stresses for untapered beams estimated from the curves of Fig. 10, are plotted against the parameter α in Figs. 17 and 18. Considering the experimental variations involved, these curves are reasonably representative of the test data The data for the equally spaced four-point loads are somewhat less regular due to difficulties in avoiding initial twist of the beam. The reduction factor, R, can be expressed in terms of α as follows:

For *end load*, with end brace

$$R = \frac{7 + \alpha}{5 + 3\alpha} \qquad (5)$$

For *equally spaced four-point loading*, with end brace,

$$R = \frac{4 + \alpha}{3 + 2\alpha} \qquad (6)$$

where,

$$\alpha = \frac{z_0}{z_1}\left(\frac{b_0 d_1}{b_1 d_0}\right)^{3/2}$$

The parameter α can also be expressed approximately, in terms of the tapers. Letting the flange taper be $T_f = /b_1/b_0$ and the web taper, $T_w = d_1/d_0$

$$\alpha' = \left[\frac{6 + \beta}{6 + \frac{T_w}{T_f}\beta}\right]\left[\frac{T_w}{T_f^3}\right]^{1/2} \qquad (7)$$

where

$$\beta = \frac{\text{area of web}}{\text{area of flange}} = \frac{A_w}{A_f} = \frac{d_0 t_w}{b_0 t_f}$$

The values of α computed from this equation differ from those found from the equation in terms of Z_0/Z_1, particularly for extreme tapers because of the approximation in expressing the section moduli in terms of total depth which causes differences in the contribution of the web area where the flange thickness is an appreciable part of the total depth at the smaller section.

While the equation for α in terms of the tapers is a less convenient form, it does indicate the relative influence of the web and flange tapers on the buckling resistance. It will be noted that the flange taper, T_f, enters as the fifth power in the radical term whereas T_w is to the first power. For a given flange taper, the web taper can be changed considerably without greatly affecting the buckling resistance. The influence of flange width on the buckling resistance was apparent from the results of tests on the specimens of the original program and later tests.

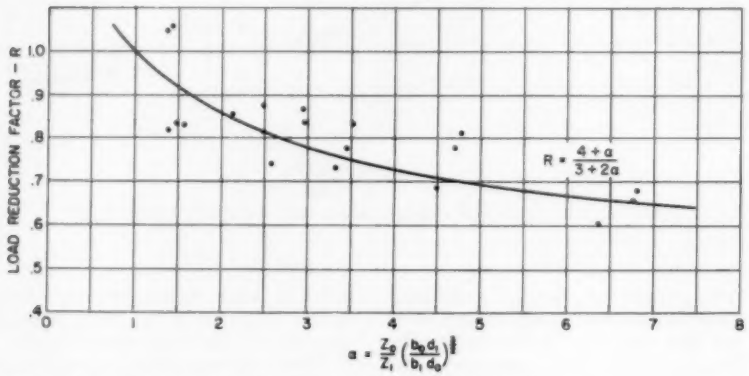

Fig. 18—Load-reduction factors for wedge beams with 4-point loading

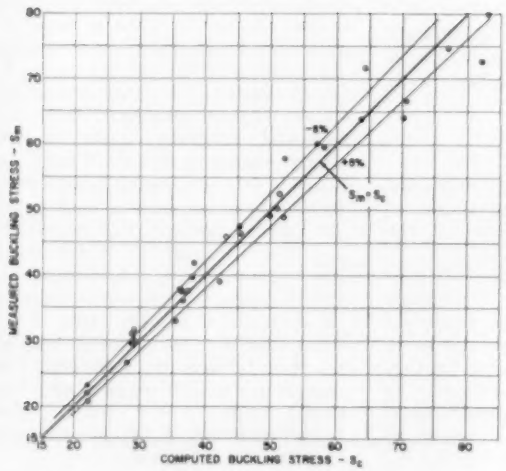

Fig. 19—Computed vs. measured buckling stress for cantilever wedge beams. End-concentrated load

A comparison of the predicted buckling stress at the support with the nominal stress determined from the observed failure loads is shown in Fig. 19. Agreement within about $\pm 5\%$ is indicated.

Application

It will be of interest to indicate the design procedure utilizing the proposed stress criteria, by the following applications. It is required to find a suitable section for a cantilever with span $L = 20$ ft., end load = 5000 lb, and end braced. Material yield point = 36,000 psi (factor of safety = 1.8).

a. Maximum bending moment = 5000(240) = 1200 in.k

$$Z \text{ req'd} = \frac{1200}{20} = 60 \text{ in.}^3$$

For rolled section, select 16 *WF* 40($Z = 64.4$) with $Ld/bt = 240(16)/7.0(0.503) = 1090$. This beam has excess buckling resistance $S_{cr.} = 94{,}000$ from curve Fig. 10 or eq 2 and would fail by yielding.

b. Suppose a 12 *WF* 27 is split diagonally and reassembled to provide

$d_0 = 20$, $d_1 = 3.90$, $t_f = 0.40$,
$t_w = 0.24$, $b_0 = b_1 = 6.5$

Then a straight beam with the same end section has

$$\frac{Ld_0}{b_0 t} = \frac{240(20)}{6.5(.40)} = 1850, S_{cr.} = 52{,}500 \text{ psi}$$

For the above dimensions,

$$Z_0 = 64.2,\ Z_1 = 8.46$$

Flexural stress at support = 1,200,000/64.2 = 18,700 psi O.K.

$$\alpha = \frac{Z_0}{Z_1}\left(\frac{b_0 d_1}{b_1 d_0}\right)^{3/2} = \frac{64.2}{8.46}\left(\frac{6.5}{6.5} \times \frac{3.9}{20}\right)^{3/2} = 0.651$$

Since α is less than 1.0, this beam can resist 100% of the straight-beam load without elastic buckling and will fail by yielding at the support.

Since this tapered beam was made from a 27-lb section, the split beam will weigh 0.675 of the straight beam selected. Saving in material = 32.5%.

c. A beam is built up with plating with both flange and web tapers having dimensions,

$d_0 = 20$ in., $b_0 = 6.25$ in., $t_f = {}^3/_8$ in.
$d_1 = 4.0$ in., $b_1 = 4.0$ in., $t_w = {}^1/_4$ in.

then $Z_0 = 60$ (as required)

$$Z_1 = 5.26$$

$$\alpha = \frac{60}{5.26}\left(\frac{6.25}{4} \times \frac{4.0}{20}\right)^{1/2} = 2.0$$

From Fig. 17 or eq 5, $R = 0.82$

Potential buckling stress of straight beam with the support

section (Ld/bt = 2045) = 46,800 psi (eq 2, Fig. 10). Therefore, $S_{cr.}$ = 0.82(46,800) = 38,400 psi. Since this stress is greater than the yield point of 36,000, beam will develop yield point before buckling and working stress of 20,000 psi is satisfactory. It will be noted that if the flange width, b, were reduced to 3 in., the critical buckling stress would be lower than yield point and, thus control. The relative weights are: straight beam at 40 lb/ft, W = 800 lb; tapered beam, W = 453 lb; saving in material = 43.4%.

The above examples indicate that a tapered section can result in a saving of material as long as failure is produced by yielding, and the capacity is not limited by elastic buckling.

It may be noted that in selecting a tapered section, the critical buckling stress is influenced to a greater extent by the flange taper than the web taper; that is, for a given web taper, the critical stress can be increased by less severe flange taper.

Summary and Conclusions

The design of a cantilever beam depends on a stress limitation at the support to (1) avoid failure by plastic yielding of the material, and (2) prevent premature failure by elastic buckling. This investigation has been concerned with the elastic buckling phenomena. The development of an empirical relation for predicting the load capacity of a wedge beam was approached by comparing the load producing elastic buckling of a tapered beam with that of a straight beam having the same section at the support. The ratio of capacities, called a "reduction factor," was expressed as a function of the support dimensions and the degree of taper.

This investigation included two phases of the cantilever design problem, namely, criteria for elastic buckling of beams with uniform section and correction factors permitting prediction of the critical stress for tapered beams.

The tests on beams having uniform section indicated that the critical stress at the support when elastic buckling was produced, can be expressed approximately, as a function of Ld/bt. This function is similar to that previously proposed for simply supported beams, differing in the constants used. For structural-grade steel with yield point of 35,000 psi, elastic buckling failure may be expected when beams subjected to end load with end brace have values of Ld/bt greater than 2500. For uniformly distributed loads, this value is increased to nearly 3700. End loading is the more severe condition for cantilevers, whereas uniformly distributed loading is more critical for simply supported beams. This difference is due to the relative bending-moment distribution. It has been shown that simply supported rolled beams fail by buckling when Ld/bt is greater than about 600.

For steels with a yield point comparable to that of structural grade, the critical stress at the support for end loading with end brace can be expressed as

$$S_{cr.} = \frac{80{,}000{,}000}{Ld/bt}, \; Ld/bt > 2500$$

This relation is unduly conservative for high-yield-point steel for which a more suitable expression for critical buckling stress is

$$S_{cr.} = \frac{110{,}000{,}000}{Ld/bt} - 7000, \; \frac{Ld}{bt} > 1000$$

These relations are limited to end loads with the tension flange braced against lateral displacement at the end. Under these conditions, standard rolled beams with normal span lengths are not likely to fail by elastic buckling unless eccentricity is involved.

While a theoretical relation for critical buckling stress for a cantilever with any dimensions might be developed by mathematical procedures as in the case of simple beams, a complicated expression involving the taper factors would be expected and approximations justified by test data would be required to provide a convenient design relation.

This investigation established empirically-derived "reduction factors" for wedge beams which permit prediction of the critical elastic-buckling stress at the support for beams with any taper, when the critical stress for an untapered beam having the same support section is known. The approximate critical buckling stress for tapered beams was found to depend upon the span length and the parameter,

$$\alpha = \frac{Z_0}{Z_1}\left(\frac{b_0 d_1}{b_1 d_0}\right)^{3/2}$$

The reduction of the critical buckling stress of a tapered beam as compared with the "potential" critical stress of an untapered beam with the same support section is expressed by

$$R = \frac{7 + \alpha}{5 + 3\alpha}$$

for beams with concentrated end loads and end brace.

If after applying this reduction factor to the "potential" critical stress of a straight beam with the same support section, the indicated stress is greater than the material yield point, the beam will fail by yielding.

Although the stresses and reduction factors can most conveniently be obtained from plotted curves, a general expression for the critical elastic stress of a tapered beam can be represented by,

$$S_{cr} = \left[\frac{110{,}000}{Ld/bt} - 7\right]\left[\frac{7 + \alpha}{5 + 3\alpha}\right] \text{ ksi}$$

where α is the taper parameter, given above.

Acknowledgment

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APPENDIX

Summary of Shop Report on Fabrication Fabrication from Rolled I Sections

(*a*) Tacked one flange to angles on cutting table.

(*b*) After marking diagonal cut on beam and setting radiograph, oxygen cutting was started 1 in. from the end of web and alternate cuts 12 in. long were made along the beam leaving 1 in. between cuts to hold the pieces together.

2. *Welding Setup*

(*a*) After removing the cutting

track, another beam of size equal to the one being cut was laid along side of the flange of the specimen beam and the flanges were tacked together.

(*b*) The 1-in. intervals remaining in the web were cut. One of the two separated pieces remained fastened to the table while the other was fastened to the beam. The kerf opened approximately 1 in. in width, but no twist developed due to rigidity of the flanges.

(*c*) The piece attached to the second beam was reversed to form the wedge shape. Clamps were used to close the kerf which opened from oxygen cutting and, if the web was not flat, clamps were used to pull down the flange.

(*d*) The web was tacked with 2-in. tack welds. The clamps were then removed, and the beam was turned over after breaking the flange tacks to the cutting table.

3. *Welding*

(*a*) Welding of the web consisted of 6-in. welds on 12-in. centers on one side with E6012 electrodes. After turning the beam over, staggered 6-in. welds on 12-in. centers were placed on the other side.

(*b*) After cooling, the holding beam was removed.

(*c*) Inspection showed very little distortion.

Fabrication from Rolled Channel Sections

1. *Cutting and Jigging*

(*a*) One side of the channel was tack welded to an angle table, flange down while the opposite side was tacked to an "H" beam. This was done to reduce vertical and horizontal distortion resulting from cutting outside the neutral axis of the channel.

(*b*) Cutting of the web diagonally by radiograph provided alternate cuts 12 in. long leaving 1 in. between cuts. The 1 in. of web remaining was severed with a hand torch and the segment welded to the "H" beam was set aside.

(*c*) A second channel was cut by the same procedure except that the removable segment was tacked to an "H" beam on the opposite side. The two pieces attached to "H" beams were then assembled by tack welding to form a wedge channel without gap.

2. *Welding*

(*a*) With the two segments assembled in a flat position, 6-in. web welds were made on 12-in. centers with E6012 $^{5}/_{32}$-in. diameter covered electrodes using 160 amp welding current.

(*b*) After removing tack welds and turning the assembly over, welding was completed on the opposite side with similar staggered welds.

(*c*) After cooling, the "H" beams were removed. An increasing amount of distortion up to 3 in. in the plane of the web was produced. This distortion in the direction of the flanges was straightened in an arbor press.

Appended comments submitted, suggested that the distortion might be minimized by prestressing in a jig and fixture which would hold the pieces during welding so that when removed from the jig the wedge channel would "spring back" to the desired shape. Another suggestion was to hold the pieces flat during welding and stress relieve the beam before removal from the jig. This would be more costly.

Fabrication of I and Channel Wedge Beams from Plate

1. The plates were cut to size by shearing. All of the wedge beams were manually assembled and tack welded prior to welding in the automatic jigs. This was done to save some set-up time involved with so few parts and varied sizes.

Some warpage was encountered in these beams, increasing in magnitude at the narrow end of the sections.

The wedge channels presented more of a problem in both assembly and welding and there appeared to be no practical way to assemble these members in the jigs.

The wedge channels were assembled in the flange-down position using pipe clamps while they were tacked to the web on the flush side.

2. *Welding.* After the parts were tacked together, the tack welds were ground flush before placing the parts in the jig for automatic welding. By tacking the flanges to the web on the flush side and flaring the flanges a small amount outward, it eliminated most of the tendency for the flanges to pull in from the automatic welds, which were continuous on the inside.

Warpage was greater in the wedge channels than the I sections and was in the opposite direction, increasing in magnitude at the small end. The size of the flanges determined the amount of warpage obtained. The web-flange weld was continuous on one side.

Some trouble was also encountered with camber and twisting of flanges due to shearing; especially with narrow flanges made of heavier material. Advantage was taken of the camber to offset warpage.

The specimens of Series IV made of T-1 steel, all of which were I sections, were fabricated in a similar manner with staggered web-flange welds 4 in. long on 8-in. centers.

Correction:

"Carbon-Dioxide-Shielded Metal-Arc Welding of Carbon-Steel Plate"

By R. J. Keller

In the January 1959 issue of the WELDING JOURNAL, Research Supplement, page 27-s, the blurb should have read:

Interpretive report prepared under the sponsorship of the WRC points out that

several types of carbon-steel plate, with carbon contents up to 0.30%,

and in thicknesses up to $1^{1}/_{2}$ in. have been successfully welded with this process

The carbon content was erroneously shown as 30%.

The Editors

Effect of Zinc Coatings on Resistance Seam Welding of Sheet Steel

Variables to be considered in the lap-seam welding of zinc-coated low-carbon steels are described and acceptable welding schedules for the materials are developed

BY C. W. VOLEK AND M. L. BEGEMAN

Introduction

This report is the second of two pertaining to the effect of zinc coatings upon the variables encountered in the resistance seam welding of coated-steel sheets. The first report compared the results of welding uncoated and zinc-coated low-carbon steel at the recommended welding conditions for uncoated steels, and established the fact that coated materials require different machine settings to produce welds of consistent high quality.[1] Only the seam welding of 22-gage (0.031-in.) sheet steels, both coated and uncoated, was dealt with in the report. It was concluded that higher welding currents are required to produce satisfactory nugget penetration, higher electrode forces are advisable, interrupted welding currents having long "off" times are undesirable and some form of continuous electrode dressing and edge-width control should be used. This report describes the changes in welding variables necessary for several other sheet thicknesses and develops acceptable lap-seam-welding schedules for these materials.

Effect of Zinc Coating on the Weld

The galvanized coating, consisting essentially of zinc, is between 0.001 to 0.004 in. thick depending upon the process used in its manufacture. Below the first layer of zinc lie several thin layers of zinc-iron alloys with a step-wise increase in the iron-to-zinc ratio as the matrix is approached.

In resistance welding, the joint (weld nugget) is produced by heat generated due to the resistance of the flow of electric current through two or more sheets of metal held together by electrode pressure. The seam weld consists of a series of overlapping spot-weld nuggets with sufficient overlap of the weld nuggets to provide a pressure-tight joint. A series of contact and internal resistances makes up the total resistance to current flow. In two-thickness seam welds, the three major resistances are the two electrode-contact resistances between the electrodes and weldments and the interface-contact resistance between the two weldments. The internal resistance of the metal is low compared to the contact resistances involved. On welding uncoated materials, the electrode-contact resistance is small and the surface heat generated is largely removed by cooling water. Therefore, the heat generated to produce the weld is primarily due to the interface-contact resistance between the two weldments. This resistance is not constant, but is dependent principally upon the degree of contact between the weldments which, in turn, is controlled by the electrode force. The higher the electrode force, the lower the contact resistance, and this results in less heat generation.

In welding zinc-coated steel, at least six layers of metal are initially present (Fig. 1) instead of two layers as in the welding of uncoated materials, thereby changing the resistance-welding conditions. Distinction must be made between the initial conditions and those which arise as welding continues; and also between those at the outside of the sheets and at the welding interface. In seam welding, sufficient heat is generated between the electrodes and coated weldments (Fig. 1, *A* and *C*) to melt the zinc coating (melting at 790° F). Since zinc has a strong affinity for copper, serious alloying and zinc pick-up occurs on the copper electrodes. This accumulation of zinc on the electrodes can be constantly broken up by knurl drives, but the electrode surface is gradually converted to a zinc-rich brass with an increase in electrical resistance. The high contact resistance between the electrodes and weldments causes an excessive amount of heat to be generated on the surface of the weld, resulting in premature surface overheating and electrode sticking. At the welding interface (Fig. 1, *B*), the major portion of the two zinc layers is melted by conducted heat from the preceding weld nugget and the heat due to resistance to current flow. The electrode pressure displaces the melted zinc

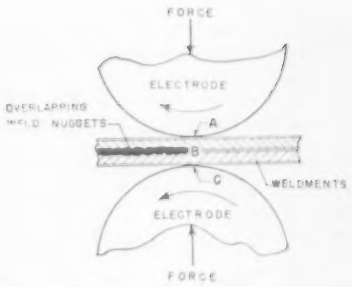

Fig. 1—Resistance seam weld between coated materials

C. W. VOLEK is Research Engineer, El Paso Natural Gas Co., El Paso, Tex., formerly graduate student, RWMA Fellowship, the University of Texas, Austin, Tex., and M. L. BEGEMAN is Professor, Mechanical Engineering, The University of Texas, Austin, Tex.

from the interface, leaving basically a steel to steel contact. This surface then proceeds to weld in the normal manner.

The preceding paragraphs have described the mechanism of resistance seam welding of galvanized steel. From this description it is apparent that the factors introduced by the zinc coating in the resistance weld are: (1) the effect the coating has on the initial contact resistance, (2) the production of a clean steel-to-steel interface welding surface at or near the melting temperature of zinc, (3) the tendency of the zinc to alloy with the electrodes and (4) the tendency of the zinc to alloy with the base metal.

Material and Equipment

The materials used in this investigation were 18- and 20-gage low-carbon galvanized-sheet steel. Other materials referred to in this report are 14- and 22-gage galvanized-sheet steel. The gage, base-metal thickness, coating thickness, and chemical analysis of these materials are given in the following table:

Gage	Base-metal thickness, in.	Coating thickness, in.	% C	Mn	P	S	Cu
22	0.0320	0.0017	0.06	0.25	0.009	0.023	0.023
20	0.0405	0.0012	0.06	0.38	0.008	0.035	0.024
18	0.0480	0.0014	0.05	0.24	0.008	0.032	0.042
14	0.0733	0.0015	0.09	0.40	0.012	0.040	0.024

The equipment used in this report is the same as that described in the previous report.[2] The electrodes used were RWMA Class II alloy, 10 in. in diameter, $^1/_2$-in. thick beveled with 15-deg chamfers to provide a face width of $^1/_4$ in.

Procedure

In resistance seam welding, the major welding variables are electrode force, current timing, welding current and welding speed. Since no practical data can be obtained by changing all these welding variables at one time, a logical sequence was needed to obtain useful results. A welding speed of 60 ipm was selected and kept constant until an acceptable welding schedule had been determined; then other speeds were investigated.

Test welds were made by lap seam welding two 1- by 36-in. strips of test material. No surface preparation was deemed necessary before making the test welds.

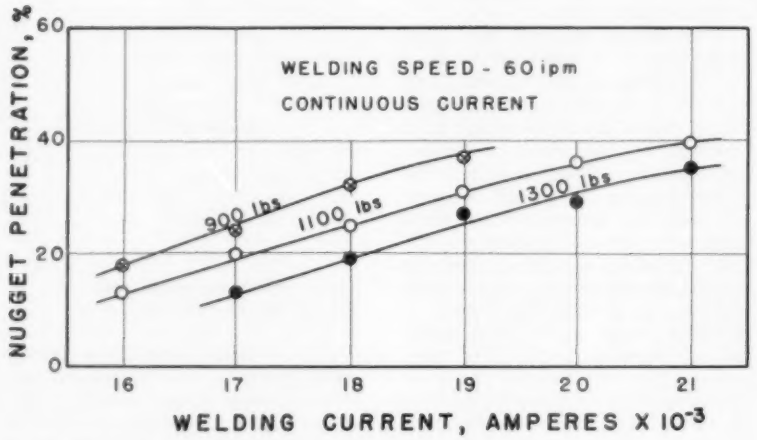

Fig. 2—Effect of current variation on nugget penetration in seam welding 18-gage galvanized steel

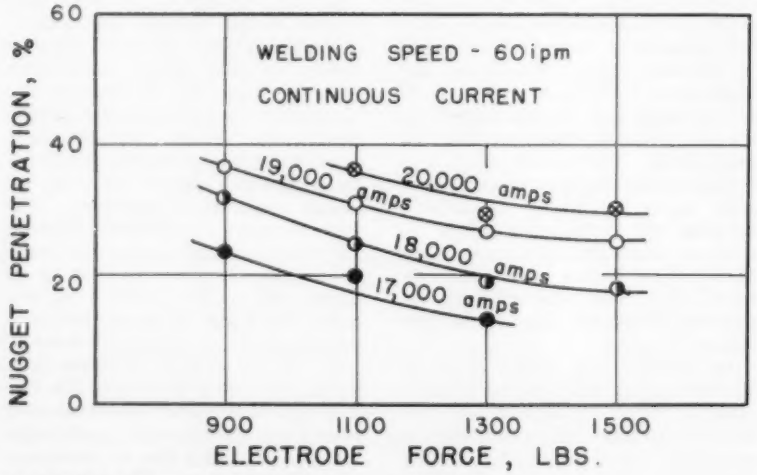

Fig. 4—Effect of electrode-force variation on nugget penetration in seam welding 18-gage galvanized steel

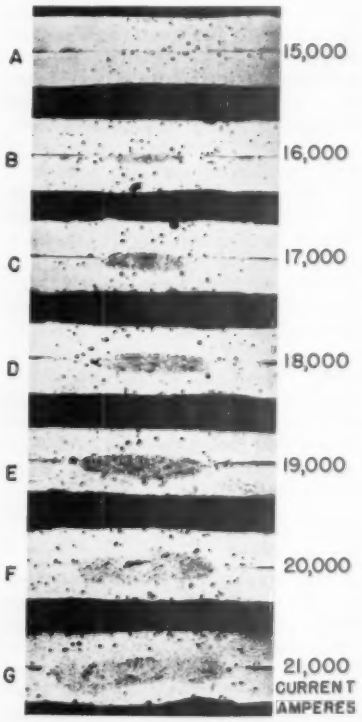

Fig. 3—Macrographs showing the result of current variation in seam welding 18-gage galvanized steel; welding speed, 60 ipm; electrode force, 1100 lb; continuous current; × 4

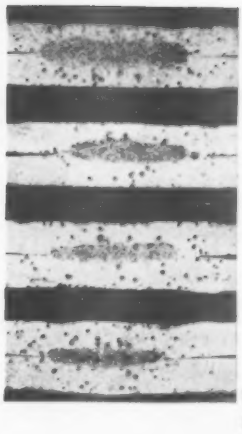

Fig. 5—Macrographs showing the effect of electrode-force variation. 18-gage galvanized steel; welding speed, 60 ipm; current, 19,000 amp; continuous current, × 4

21,000	ELECTRODE STICKING		39	35	34
20,000			35	29	30
19,000		37	31	27	25
18,000		33	25	19	19
17,000	41	24	20	13	0
16,000	31	18	14	0	0
15,000	15	0	0	0	0
14,000	11	0	0	0	0
AMPERES / POUNDS	700	900	1100	1300	1500

— WELD WITH NO POROSITY
— WELD WITH OCCASIONAL POROSITY
— WELD WITH TRANSVERSE CRACKS
NO. IN BLOCK — PENETRATION, %

Fig. 6—Relationship of porosity, cracking, penetration, electrode force and welding current in seam welding 18-gage galvanized steel. Welding speed, 60 ipm; continuous current

20,000	44	51	ELECTRODE STICKING
19,000	38	43	
18,000	25	34	47
17,000	19	27	43
16,000	4	12	33
15,000	0	2	18
AMPERES / COOL TIME	1	2	3

— WELD WITH NO POROSITY
— WELD WITH OCCASIONAL POROSITY
— WELD WITH TRANSVERSE CRACKS
NO IN BLOCK — PENETRATION, %

Fig. 8—Relationship of porosity, cracking, cool time and welding current in seam welding 18-gage galvanized steel. Heat time, 5 cycles; electrode force, 1100 lb; welding speed, 60 ipm

Two metallurgical specimens, one X-ray specimen and one corrosive specimen were taken from each weld. The metallurgical inspection consisted of measuring nugget penetration and width, and inspecting the welds for defects such as porosity, cracking, inclusions, shrinkage and nonsymmetrical weld nuggets. Nugget penetration is defined as the ratio of the thickness of the weld nugget (a low-carbon martensitic structure) to the total thickness of the joint. X-ray inspection indicated the porosity and possible cracks present in each weld. Corrosion specimens were placed in a 100% humidity atmosphere chamber at room temperature and inspected periodically. Tensile and pillow tests were performed on selected welds to determine their shear strength and pressure-holding qualities.

A continuous current timing was selected because the previous study of welding 22-gage galvanized steel indicated a trend toward the use of continuous current for optimum welds. A series of welds was made with variations in welding current at each of several different settings of electrode force. The optimum electrode force was determined from data obtained from these welds. With the established electrode force, a series of welds was made with a variation in welding current at each of the several current-time settings. From these data, the optimum current timing and welding current were determined.

An accelerated electrode-life test was run to determine the effect of electrode alloying and electrode pick-up on weld quality when seam welding galvanized steel. This was performed by seam welding 400 ft of material using welding conditions which gave good welds but conditions likely to emphasize electrode pick-up. Metallurgical specimens were cut at every 20 ft and inspected.

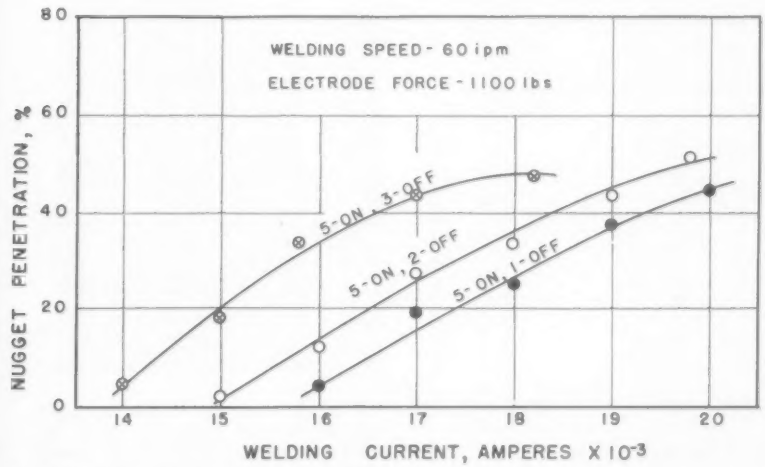
WELDING SPEED - 60 ipm
ELECTRODE FORCE - 1100 lbs
NUGGET PENETRATION, % 80 60 40 20 0
5-ON, 3-OFF
5-ON, 2-OFF
5-ON, 1-OFF
14 15 16 17 18 19 20
WELDING CURRENT, AMPERES X 10-3

Fig. 7—Effect of cool-time variation on nugget penetration in seam welding 18-gage galvanized steel

Discussion of Results

In the experimental work of this report, 18- and 20-gage galvanized steels were investigated separately according to the procedure previously described. Since both materials were found to act similarly, the results of the two investigations are presented together. Also, to avoid confusion and repetition, the curves indicated with the discussion apply only to the 18-gage steel. Similar curves demonstrating the results of welding 14- and 20-gage galvanized steel are presented in the Appendix along with some additional curves pertaining to 18-gage material.

Use of Continuous Current

A study of the use of continuous current was made in welding both thicknesses of material to determine the optimum electrode force for each material and to develop a welding schedule using continuous current. Figure 2 shows the results of welds made in 18-gage galvanized steel with variations in current at electrode forces of 900, 1100 and 1300 lb. The maximum penetrations (40%) are substantially lower than those obtainable in uncoated materials. For each electrode force, the current magni-

tude was found to be limited by excessive surface heating and electrode sticking. The macrographs in Fig. 3 show the results of current variation at an electrode force of 1100 lb in welding 18-gage galvanized steel at a welding speed of 60 ipm. The round dark structures are balls of martensite, which are discussed further under "Metallurgical Analysis." Weld A in Fig. 3 shows the effect of insufficient heating to form a weld nugget. Tensile-shear tests showed this weld to possess full strength, indicating only soldering of the low-melting zinc with the iron. Welds B through F show a steady increase in nugget penetration with increased current. Weld G illustrates the effect of extreme weld overheating which results in nugget distortion and shrinkage. Under these conditions, the heat balance in the weld area has seriously been altered, and further increases in current produce poor welds.

Figure 4 shows the effect of a variation in electrode force on weld penetration in welding the 18-gage material, the current being held constant. The drop in penetration at higher electrode pressures is the result of decreased interface-contact resistance which results in less heat generation. The macrographs in Fig. 5 show the decrease in nugget penetration with increased electrode force at a constant current of 19,000 amp.

Porosity and cracking present in continuous current welds made in 18-gage material are indicated in Fig. 6. From this chart, we find that most welds made with continuous current have a small amount of porosity, with transverse cracks occurring at higher penetrations. Results for welding 20-gage material indicated similar trends (Appendix, Fig. 25). These cracks are discussed further under "Defects Found in Welds."

Use of Interrupted Current

In seam welding, the optimum time setting is the most difficult welding condition to determine. Timing conditions are referred to as "heat" time and "cool" time or

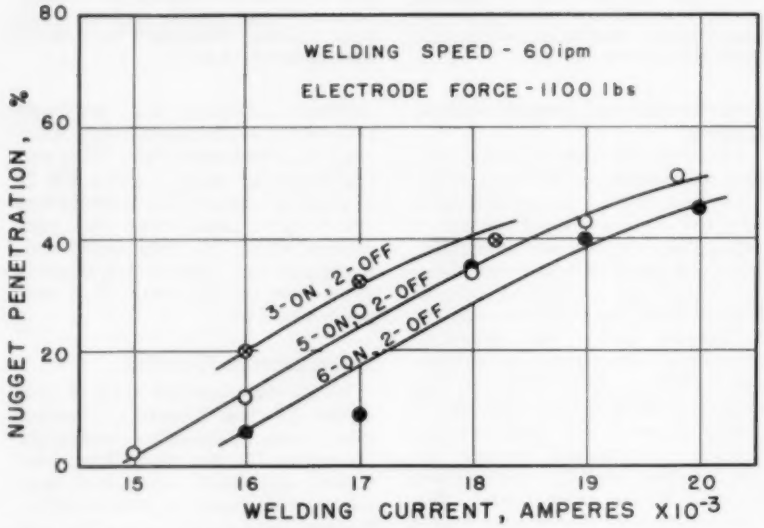

Fig. 9—Effect of heat-time variation on nugget penetration in seam welding 18-gage galvanized steel

20,000	ELECTRODE STICKING		51	46
19,000		41	43	40
18,000	40	40	34	36
17,000	33	35	27	9
16,000	20	8	12	6
15,000	0	5	2	0
AMPERES				
HEAT TIME	3	4	5	6

— WELD WITH NO POROSITY
— WELD WITH OCCASIONAL POROSITY
— WELD WITH TRANSVERSE CRACKS
NO. IN BLOCK — PENETRATION, %

Fig. 10—Relationship of porosity, cracking, heat time and welding current in seam welding 18-gage galvanized steel. Cool time, 2 cycles; electrode force, 1100 lb; welding speed, 60 ipm

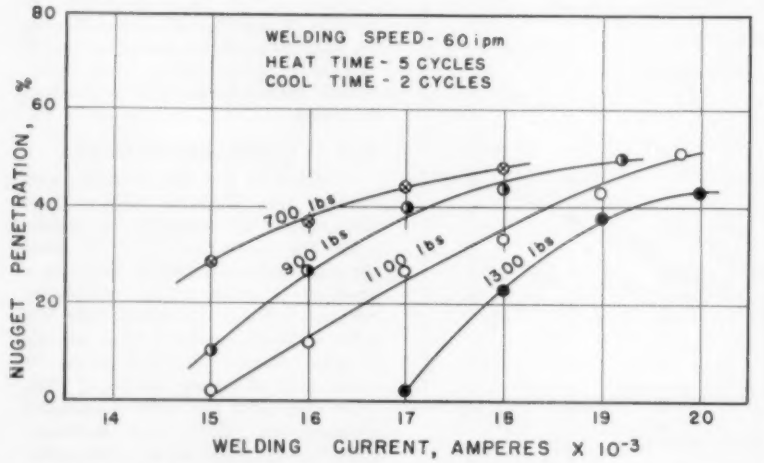

Fig. 11—Effect of welding current and electrode force on nugget penetration in seam welding 18-gage galvanized steel

20,000	ELECTRODE STICKING		51	43	38
19,000		50	43	38	27
18,000	48	44	34	23	0
17,000	44	40	27	2	0
16,000	37	28	12	0	0
15,000	28	10	2	0	0
AMPERES					
POUNDS	700	900	1100	1300	1500

— WELD WITH NO POROSITY
— WELD WITH OCCASIONAL POROSITY
— WELD WITH TRANSVERSE CRACKS
NO. IN BLOCK — PENETRATION, %

Fig. 12—Relationship of porosity, cracking, penetration, electrode force and welding current in seam welding 18-gage galvanized steel. Heat time, 5 cycles; cool time, 2 cycles; welding speed, 60 ipm

"on" time and "off" time. The heat time determines the amount of heat generated in the weld, while the cool time determines the nugget to nugget spacing and the resulting shunting effects.

With the electrode force held constant at 1100 lb (the optimum electrode force found in the study of continuous current), welds were made under different timing conditions in the 18-gage material. For each current-time setting, the current magnitude was limited by excessive surface heating and electrode sticking. Figure 7 shows the effects of increasing the cool time while holding the heat time at 5 cycles. The increase in cool time has reduced the shunting effects; the result being a higher nugget penetration at the same current. Welds made with heat times of 4 cycles and 3 cycles gave similar results with a lower current variation (Appendix, Figs. 29 and 30). Figure 9 shows the effects of an increase in heat time while holding the cool time at 2 cycles. The increase in heat time was found to have little effect on nugget penetration but it did increase the current variation for welds having acceptable properties. Again the welds showed cracking defects at the higher nugget penetrations illustrated in Figs. 8 and 10.

To assure that the optimum electrode force was selected for welding the 18-gage material, a series of welds was run at 5 cycles heat time and 2 cycles cool time with variations in welding current at several values of electrode force. The results of these runs are shown in Figs. 11 and 12. From a study of nugget penetration, porosity, strength and weld appearance, an electrode force of 1100 lb was found to give the best welds, as in the use of continuous current.

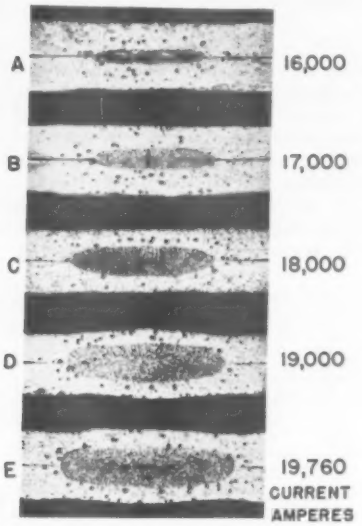

Fig. 13—Macrographs showing the result of current variation in seam welding 18-gage galvanized steel. Welding speed, 60 ipm; electrode force, 1100 lb; heat time, 5 cycles; cool time, 2 cycles. × 4

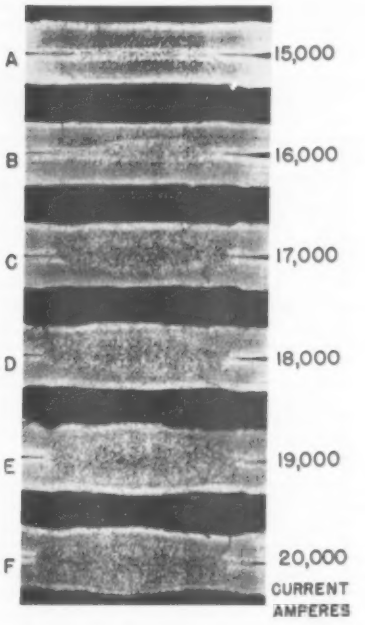

Fig. 14—Macrographs showing the result of current variation in seam welding 20-gage galvanized steel. Electrode force, 1000 lb; welding speed, 60 ipm; heat time, 4 cycles; cool time, 2 cycles. × 5

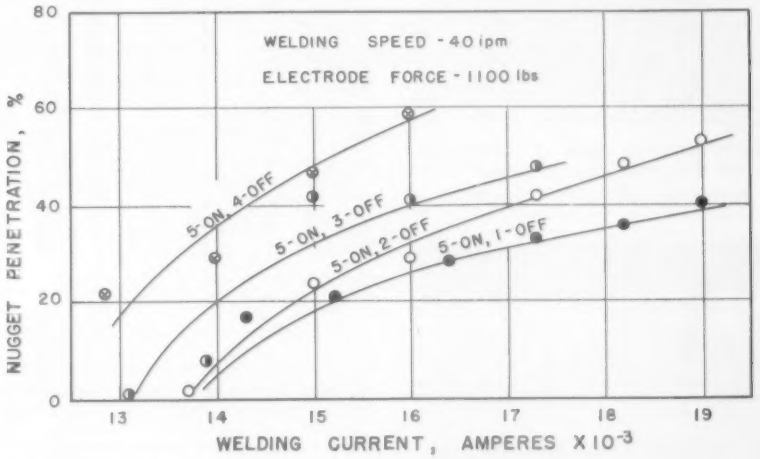

Fig. 15—Effect of cool-time variation on nugget penetration in seam welding 18-gage galvanized steel

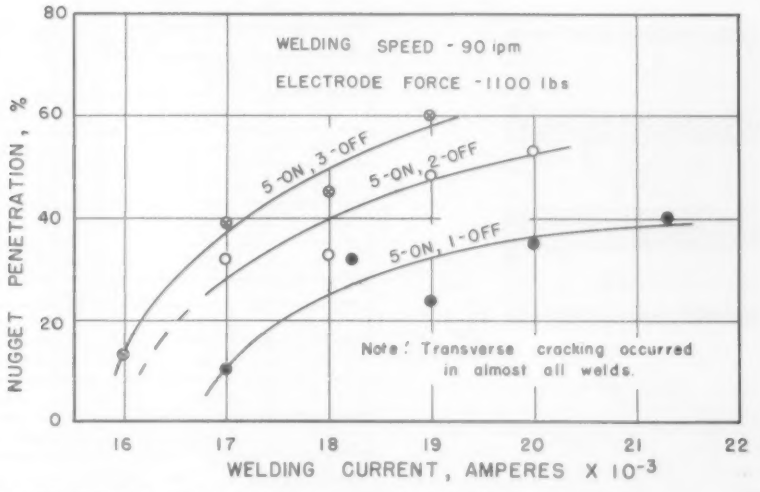
WELDING SPEED - 90 ipm
ELECTRODE FORCE - 1100 lbs
5-ON, 3-OFF
5-ON, 2-OFF
5-ON, 1-OFF
Note: Transverse cracking occurred in almost all welds.
NUGGET PENETRATION, %
WELDING CURRENT, AMPERES X 10-3

Fig. 16—Effect of cool-time variation on nugget penetration in seam welding 18-gage galvanized steel

A series of macrographs is shown in Fig. 13 demonstrating the effect of current variation in welding 18-gage galvanized steel. The variables held constant were: electrode force, 1100 lb; heat time, 5 cycles; cool time, 2 cycles; and welding speed, 60 ipm. In this case, the weld nuggets are larger and more symmetrical than those made with continuous current, see Fig. 3. This indicates that a better heat balance had been obtained with interrupted current. Again at higher currents, the welds begin to show overheat conditions as demonstrated by the shrinkage defect in weld E of Fig. 13.

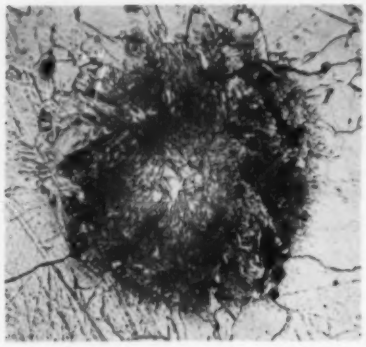

Fig. 17—Microstructure of a dark area in the weld heat-affected zone. × 330. (Reduced by 1/4 upon reproduction)

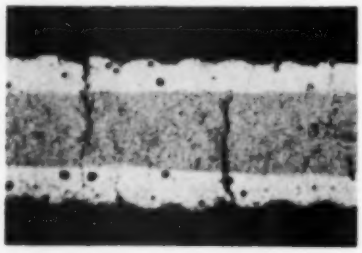

Fig. 18—Longitudinal section of a galvanized seam weld showing transverse cracks. × 5

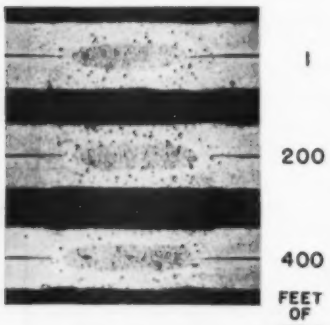

Fig. 21—Macrographs of an accelerated test of the effect of electrode life on nugget size; 18-gage galvanized steel. Electrode force, 1100 lb; welding speed, 60 ipm; welding current, 17,000 amp; heat time, 5 cycles; cool time, 2 cycles. × 4

Fig. 19—Print from a radiograph of a galvanized seam weld showing transverse cracks. × 1.7

Another series of macrographs is shown in Fig. 14 which demonstrates the effect of current variation in welding 20-gage galvanized steel. The variables held constant were: electrode force, 1000 lb; heat time, 4 cycles; cool time, 2 cycles; and welding speed, 60 ipm. Weld nuggets are harder to define in the 20-gage material than those in the 18-gage material. Weld A shows the beginning of the weld nugget along the interface with heat-affected

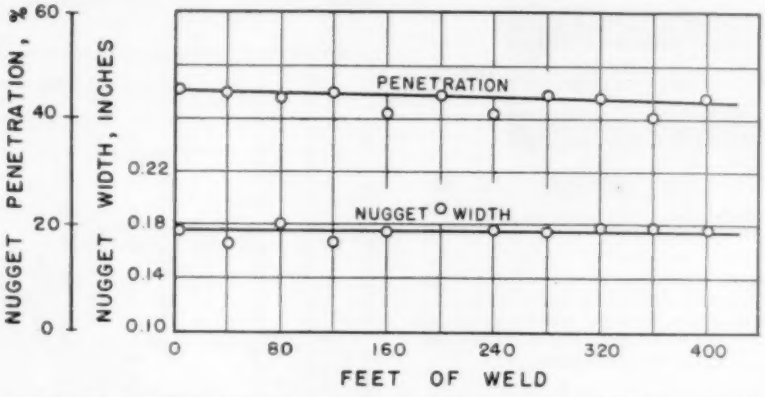

Fig. 20—Effect of electrode use on nugget penetration and nugget width in seam welding 18-gage galvanized steel. Heat time, 5 cycles; cool time, 2 cycles; electrode force, 1100 lb; welding current, 1700 amp; welding speed, 60 ipm

GAGE	SHEET THICKNESS IN.	ELECTRODE FACE WIDTH IN.	ELECTRODE FORCE LBS.	CURRENT TIMING CYCLES ON	CURRENT TIMING CYCLES OFF	WELDING SPEED IPM.	WELDING CURRENT AMPS.
INTERRUPTED CURRENT (60 cycle)							
22	0.034	1/4	1200	5	1	60	18,000
20	0.041	1/4	1000	4	2	60	16,000
18	0.049	1/4	1100	5	2	60	18,000
18	0.049	1/4	1100	5	1	90	19,000
14	0.075	5/16	1600	8	2	30	19,000
14	0.075	5/16	1600	10	2	45	21,000
CONTINUOUS CURRENT (60 cycle)							
22	0.034	1/4	1200			60	16,000
20	0.041	1/4	1000			60	17,000
18	0.049	1/4	1100			60	19,000
14	0.075	Use	Not Recommended				

Note: Use fitted knurl drives.

Fig. 22—Seam-welding schedule for welding pressure-tight joints in galvanized steel

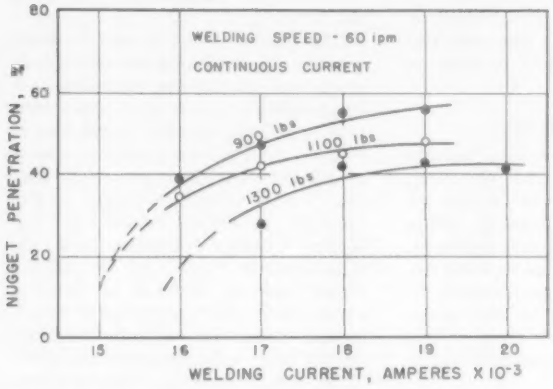

Fig. 23—Effect of current on nugget penetration in seam welding 20-gage galvanized steel

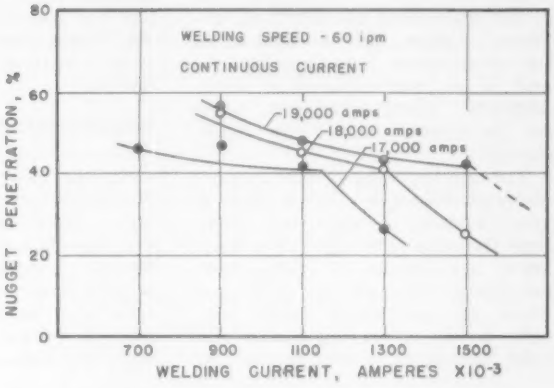

Fig. 24—Effect of electrode force in seam welding 20-gage galvanized steel

bands on both sides of the nugget. Welds B through F show the increase in nugget size as the current is increased. Overheating conditions are indicated in weld F by the shrinkage defect and distorted weld surface.

Effect of Welding-Speed Variation

To investigate the effect of welding speed on seam-weld quality, a series of welds was made at speeds of 40 and 90 ipm in the 18-gage galvanized steel. At each welding speed, seam welds were made at several different values of cool time while varying the welding current. The data obtained from these welds indicate that seam welds made at higher welding speeds: (1) require higher welding currents to obtain seam welds of the same weld-nugget penetration; (2) have a shorter welding-current range for obtaining welds of acceptable nugget penetrations; (3) require smaller cool-time to heat-time ratios for the best seam welds; and (4) show a stronger tendency to develop transverse cracks. Curves showing these results are found in Figs. 15 and 16.

Metallurgical Analysis

The macrographs shown in Figs. 13 and 14 indicate slightly different structures of the two sheet thicknesses. Although the analyses of the two are approximately the same, their microstructure is different. The macrographs of welds in 18-gage steel (Fig. 13) have well-defined weld nuggets surrounded by a heat-affected zone containing a number of small carbon-rich dark areas embedded in a ferrite matrix. Upon high magnification (see Fig. 17), these dark areas were found to consist of martensite around a nucleus of retained austenite. The characteristic needle-like martensitic structure projecting into the austenite is clearly revealed by etching. These structures had an average Vickers hardness number of 384 which corresponds to a Rockwell "C" hardness of 46. A steel with the carbon content investigated cannot have so high a hardness, indicating that the carbon has segregated into small areas and was trapped by the fast cooling of the weld. The average base-metal hardness was Rockwell "B" 64 and the average nugget hardness was Rockwell "C" 18.

The amount of austenite present in these areas depends upon the rate of cooling following welding. This was confirmed by heating strips of 18-gage galvanized steel in a furnace and rapidly quenching from different temperatures.

AMPERES / POUNDS	700	900	1100	1300	1500
20,000	ELECTRODE STICKING			41	
19,000		56	48	43	43
18,000		55	45	42	25
17,000	46	47	42	28	0
16,000	35	39	35	0	0
15,000	31	0	0	0	0
14,000	31	0	0	0	0

— WELD WITH NO POROSITY
— WELD WITH OCCASIONAL POROSITY
— WELD WITH TRANSVERSE CRACKS
NO. IN BLOCK — PENETRATION, %

Fig. 25—Relationship of porosity, cracking, penetration, electrode force and current in seam welding 20-gage galvanized steel. Welding speed, 60 ipm; continuous current

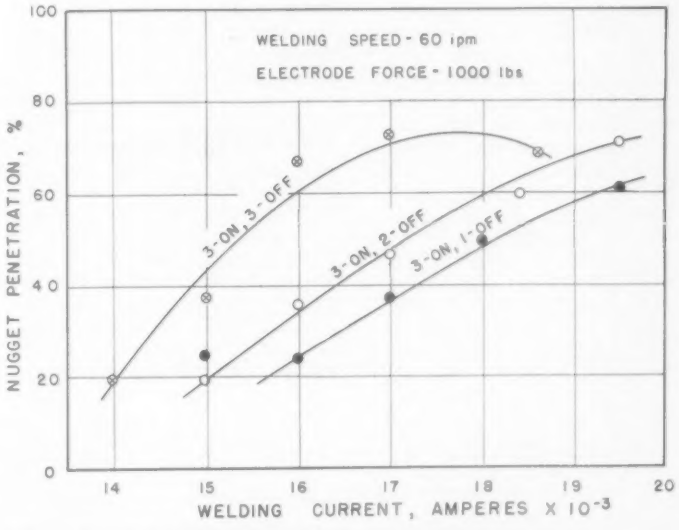

Fig. 26—Effect of cool-time variation on nugget penetration in seam welding 20-gage galvanized steel

Round martensitic areas appeared in the specimens quenched at between 1400 to 1600° F, that is, in the intercritical zone between A_1 and A_3 on the iron-carbon phase diagram. These structures cause no detrimental effect on weld strength.

The macrographs of the 20-gage material shown in Fig. 4 have a larger number of small dark areas than the other material. The dark areas are zones of high-carbon martensite, common to resistance welds in low-carbon steel. The light bands, appearing across the weld nugget in welds A and B, indicate that a small amount of zinc has alloyed near the surface of the sheets and has changed the etching pattern of that portion of the weld.

Defects Found in Welds

Defects found in welds include shrinkage, porosity and cracking. Shrinkage occurred in welds at high current settings and in welds with insufficient electrode pressure. Porosity, a defect found to some extent in most welds, is believed to arise from the zinc and zinc gases trapped in the weld area. Generally the amount of porosity which occurred was insufficient to weaken the weld.

The major defect found in seam welding 18- and 20-gage galvanized steel was transverse cracking. A longitudinal section of a weld containing these cracks is shown in Fig. 18 and a print from a radiograph showing these cracks in Fig. 19. These cracks occurred in the 18-gage material tested at the higher nugget penetrations as illustrated in Figs, 6, 8, 10 and 12. Some alloying of zinc in steel is expected in the weld nugget which would cause the weld to be more brittle than welds in uncoated steel. This, combined with extreme stresses set up along the length of the weld by the fast quenching rate imposed by water-flood cooling, is probably the cause of the transverse cracks. Due to the orientation of these cracks, they do not affect the tensile-shear strength of weld coupons; however, they do affect the pressure-holding qualities of the seam weld, which is measured in the pillow test. In this test, pinhole leaks appeared at low pressures in the welds containing cracks, and final failure occurred at a reduced load. The cracking tendency increased in welds made at a higher electrode speed of 90 ipm. At a slower welding speed of 40 ipm, the cracking tendency decreased and pillow tests indicated an improvement in pressure strength. The optimum welding conditions for high-pressure applications are found at low-nugget penetrations and involve close control of welding current. For atmospheric pressure applications and at moderately increased pressures, the welds containing the transverse cracks are still acceptable, possessing maximum tensile-shear strength.

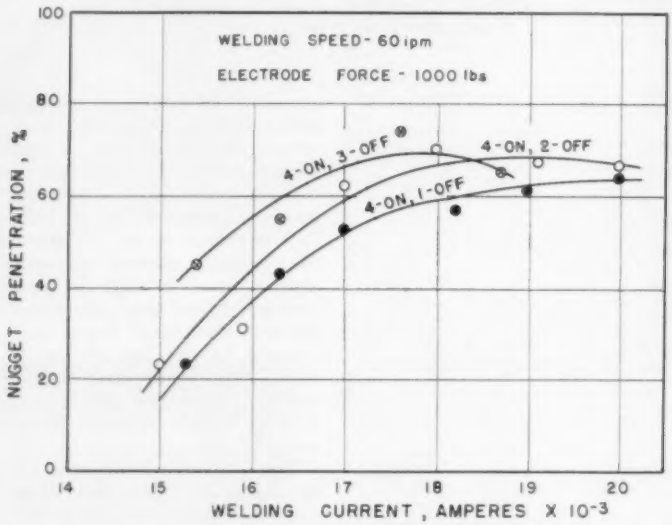

Fig. 27—Effect of cool-time variation on nugget penetration in seam welding 20-gage galvanized steel

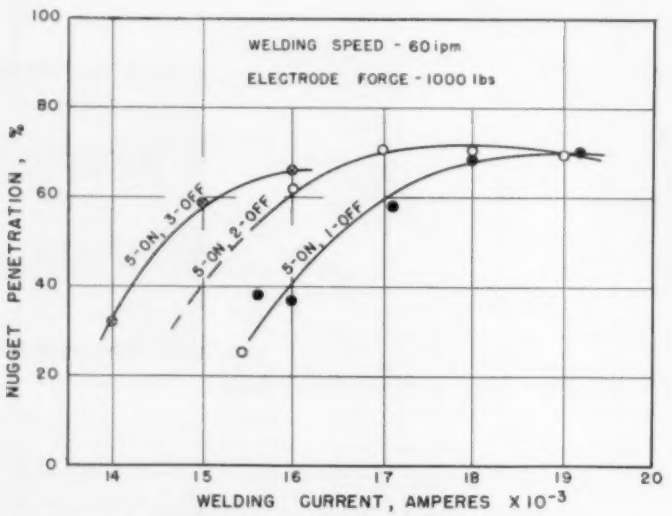

Fig. 28—Effect of cool-time variation on nugget penetration in seam welding 20-gage galvanized steel

Electrode Life

In welding zinc-coated steels, alloying and electrode pick-up occur on the copper-alloy electrodes from the zinc coating. It was felt to be important to determine how rapidly this effect occurred and whether deterioration of weld quality could be noted after a limited footage of weld had been made, under conditions likely to emphasize zinc pick-up. A $^{7}/_{32}$-in. face width knurl drive was provided which held the electrode width constant. The test was performed on 18-gage galvanized steel. After a few feet of weld were run through the electrodes to stabilize welding conditions, a continuous run of 400 ft of weld was made. Figure 20 shows the effect of electrode use, in terms of the number of feet of material welded, on nugget pene-

tration and nugget width. Macrographs of weld sections cut after 1200 and 400 ft of weld are shown in Fig. 21. From this test no noticeable effects were detected on weld quality, indicating that several thousand feet of weld can be expected from a set of electrodes without retrimming.

Corrosion Resistance

The corrosion resistance of any material is difficult to evaluate since it depends upon such factors as environment, temperature, use, etc. In this study, 1- x 4-in. weld specimens were placed in a chamber giving 100% humidity atmosphere at room temperature for several months and were inspected periodically for corrosion. The welds showed a small amount of pitting or galvanic corrosion after a week, with the pits afterwards increasing in size very slowly with time. Little galvanic corrosion was expected since zinc lies very close to the uncoated weld metal and serves as an anode in a galvanic cell. Any alloying of zinc and iron on the weld surface would also make the weld more corrosion resistant than plain uncoated steel.

There was no noticeable difference in the corrosion resistance of welds made under different conditions of electrode force and current. The corrosion resistance of the weld areas in the galvanized steel was greater than that of the sheared edges of the test specimens. Probably 90% of the corrosion resistance of the galvanized steel still remained after seam welding.

Conclusions

The preceding study of the galvanized seam weld has led to the following conclusions:

1. The maximum weld penetrations obtainable in galvanized sheet steel are lower than those in uncoated sheet steel.

2. Interrupted current produces better quality welds than continuous current and higher heat-time to cool-time ratios are required for galvanized steel than for similar but uncoated steel.

3. Compared to uncoated steels, closer control is required on the welding variables to assure high-quality welds.

4. The seam-welding schedule presented in Fig. 22 is given as an approximate guide for welding 14-, 18-, 20- and 22-gage galvanized sheet steel.

5. A knurl drive is necessary to assure good contact between the electrodes and base metal and to prevent zinc buildup on the electrodes.

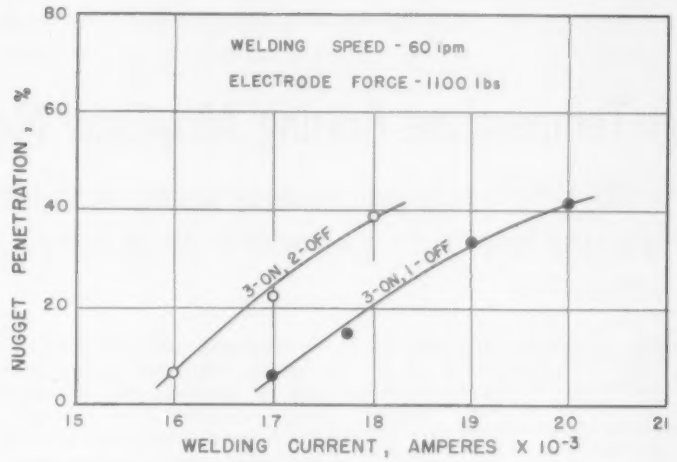

Fig. 29—Effect of cool-time variation on nugget penetration in seam welding 18-gage galvanized steel

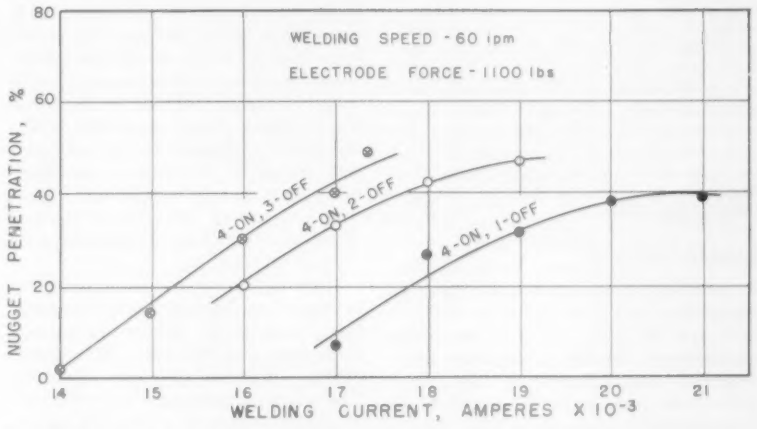

Fig. 30—Effect of cool-time variation on nugget penetration in seam welding 18-gage galvanized steel

6. The electrode face width should be kept constant by the use of fitted knurl drives to prevent electrode mushrooming and to assure consistent welds.

7. A major defect found in galvanized welds is transverse cracking. The defect becomes pronounced at higher welding speeds and high nugget penetrations.

8. Although most of the zinc coating is expelled from the weld area, the weld surface shows corrosion resistance approximately 90% that of the original material.

9. An accelerated test of electrode life suggests that several thousand feet of weld could be expected from a set of electrodes before retrimming is necessary.

APPENDIX

A number of curves was omitted from the report because of the large number of illustrations. It is thought advisable to make these curves available to those interested since plotted weld characteristics are difficult to describe in words. Figures 23 to 28 show the results obtained in the investigation of 20-gage galvanized steel. Figures 29 and 30 are additional curves showing the effect of cool-time variation on nugget penetration for 18-gage material.

For the seam welding of 14-gage galvanized steel, the electrodes used were RWMA Class II alloy, 10 in. in diameter, $^1/_2$ in. thick, beveled with 10-deg chamfers to provide a face width of $^5/_{16}$ in. They were driven by $^5/_{16}$-in. face width knurl drives on both the upper and lower electrodes.

References

1. Allen, W. J., and Begeman, M. L., "Seam Welding Galvanized Steel," THE WELDING JOURNAL, 37(4), 1385–1435 (1958).

2. Allen, W. J., and Begeman, M. L., *op. cit.*, 1385–1435.

High-Temperature Brazing Alloy-Base Metal Wetting Reactions

Wettability of high-temperature alloys by brazing alloys found to decrease as the brazing temperature is increased above the nominal level

BY W. FEDUSKA

SYNOPSIS. Reactions between five high-temperature base metals and six high-temperature brazing alloys have been determined in three different atmospheres at nominal and superheat brazing temperature levels. The general effects produced by the variable test conditions have been reviewed to determine which combinations produced ideal and which produced poor wetting. In addition, relative "wetting index" ratings have been established for the 118 test combinations employed. Generally, the wettability of high-temperature alloys by brazing alloys decreased as the brazing temperature was increased above the nominal level. This behaviorism is attributed to an increase in reactivity between the brazing alloy elements and the base metal at the higher brazing temperature.

Introduction

In producing equipment for steam turbines, land gas turbines, aviation gas turbines, integral aircraft components, rocketry, and nuclear reactors, manufacturers are required to join a variety of high-temperature alloys which have been produced in a myriad of shapes and sizes. Oftentimes, in joining these components, fusion welding or mechanical attachment techniques may not be feasible, due to the size, shape or materials to be joined. In these cases, utilization of another method of joining is imperative.

High-temperature alloy brazing is a promising technique for joining intricate components of equipment operating at elevated temperature. Here, high-temperature alloy brazing refers to a method of metal joining by fusion of alloys which have melting temperatures in the range of about 1800–2200° F. This temperature range is lower than the melting temperature or temperature range of the metals or alloys being joined, but is sufficiently high to allow use of the joined components at operating temperatures as high as 1800° F.[1]

Although high-temperature alloy brazing has already been successfully applied to numerous joining problems, insufficient knowledge exists concerning the process. Therefore, a program was initiated which was aimed at obtaining an insight into the fundamental mechanisms controlling high-temperature alloy brazing. This investigation presents the results of one phase of the program dealing with high-temperature brazing alloy-base metal wetting reactions.

Wettability is a basic factor involved in any brazing operation. This property may be defined as the ability of a liquid brazing alloy to flow over a base-metal surface while elements of the brazing alloy superficially diffuse into and alloy with it.

The spreading ability of a liquid brazing alloy is dependent upon its surface tension and the interaction between elements of the base metal and the brazing alloy. This interaction is incorporated into the interfacial tension between the brazing alloy and base metal. Spreading ability, under ideal conditions, is also dependent upon the surface energy of the clean base-metal surface. Superficial alloying depends upon the presence of an element, or elements, in the brazing alloy and base metal which exhibits some solubility at brazing temperature.

In this paper, the results of a survey conducted on a variety of high-temperature brazing alloy-base metal wetting reactions are presented. Specifically, the investigation presents wetting reactions for 118 different combinations of high-

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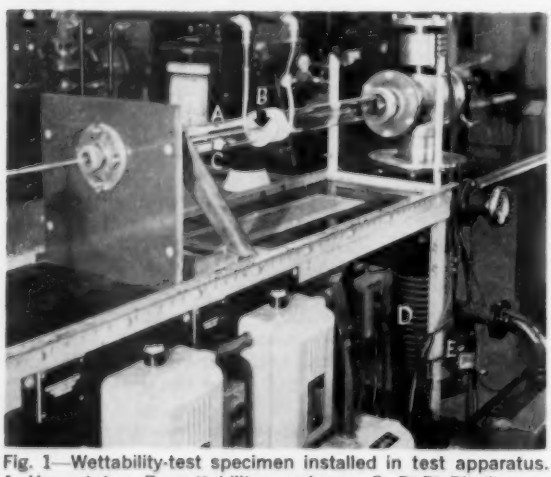


Fig. 1—Wettability-test specimen installed in test apparatus. A, Vycor tube; B, wettability specimen; C, Pt-Pt Rh thermocouple; D, MC-275-01 diffusion pump; E, MB-200 booster pump

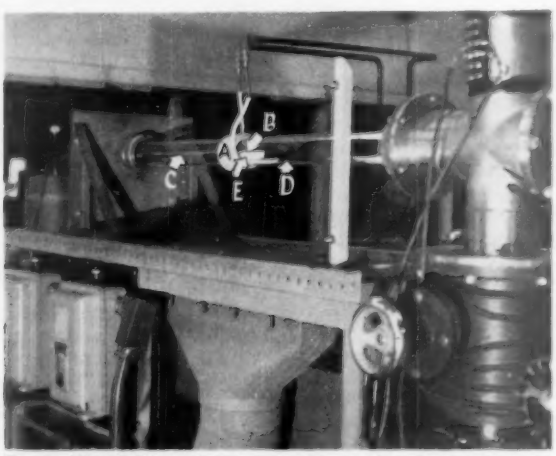


Fig. 2—Wettability-test specimen in position for testing. A, induction coil; B, wettability specimen; C, Pt-Pt Rh thermocouple; D, Vycor tube; E, alundum holding fixture

Table 1—Compositions of High-Temperature Base Metals and Brazing Alloys Used in the Wettability Tests

Base-metal designation	Nominal composition, % C	Mn	Si	Cr	Ni	Co	Mo	W	NbTa	Ti	Al	Fe
AISI 410, martensitic stainless steel	0.15 max.	...	...	11.5–13.5	....	...	...	...	....	...	...	Bal.
AISI 347, austenitic stainless steel	0.08 max.	...	...	17.0–19.0	9.0–13.0	...	...	...	0.80 min	...	...	Bal.
Iron-base, high-temperature alloy	0.03	0.8	0.8	13.5	26.0	...	3.0	...	....	1.6	0.1	Bal.
Nickel-base, high-temperature alloy	0.04	0.7	0.3	15.0	Bal.	...	...	...	0.9	2.5	0.9	7.0
Cobalt-base, high-temperature alloy	0.10	1.5	0.7	20.0	10.0	Bal.	...	15.0	....	...	...	1.0

Brazing alloy	Designation	C	Mn	Si	Cr	Ni	B	S	P	Zr	Ag	Al	Fe	Powder mesh	Alloy liquidus temp, °F	Nominal brazing temp, °F	Superheat brazing temp, °F
Ni-Cr-Si-B-C	Alloy 1	0.76	...	4.60	13.67	Bal.	3.13	...	...	...	...	...	4.29	—325 min	1875	1980	2055
Ni-Cr-Si-B-C	Alloy 2	0.80	...	4.00	15.00	Bal.	4.00	...	...	...	...	...	4.00	—150 min	1870	1960	2050
Ni-Cr-Si	Alloy 3	0.17	0.81	9.91	18.95	Bal.	...	0.005	0.005	0.03	...	0.08	0.49	—140 min	2030	2120	2210
Ni-Cr-Si	Alloy 4	0.03	...	11.25	19.00	Bal.	...	...	...	...	...	...	1.10	—100 min	2065	2160	2250
Ag-Mn	Alloy 5	...	15.00	...	...	...	...	...	...	...	85.0	...	...	— 80 min	1760	1850	1940
Ni-Si-B	Alloy 6	...	...	4.58	...	Bal.	2.89	...	...	...	...	...	...	—150 min	1975	2070	2160

temperature base metals, high-temperature brazing alloys and protective environments, at nominal or superheat brazing temperatures.

Materials

The base metals and dry, commercial brazing-alloy powders used in the wettability tests are listed in Table 1, along with their chemical compositions and brazing temperatures. Minimum mesh sizes ranged from minus 80 to minus 325 for the different brazing-alloy powders, as indicated in the table.

Procedure

Wettability specimens, approximately $1^1/_8$ by $1^1/_8$ by $^1/_4$ in., were prepared from each base metal. A $^1/_{16}$-in. diam by $^1/_8$-in. deep thermocouple hole was drilled at the center of one edge of each sample with the exception of the cobalt-base alloy which was too hard to drill. One face, $1^1/_8$ by $1^1/_8$ in., of each wettability sample was polished to a No. 1 metallographic paper finish and all other surfaces were cleaned of traces of oxides.

Each sample was separately degreased as follows: washed with warm water, dried with alcohol, degreased in trichloroethylene, rinsed with alcohol and dried. Dry brazing-alloy powder, equivalent to 0.33 cm^3 in calculated average volume, was centrally placed on the polished surface of the sample and the wettability specimen was then positioned on an alundum base, inside a Vycor tube, at the location of an induction coil. A platinum-platinum rhodium thermocouple was inserted into the hole of the plate and the Vycor tube was sealed off, as shown in Figs. 1 and 2. Temperatures of the cobalt-base- alloy samples were measured with an optical pyrometer.

During testing, the wettability specimens were heated to either the nominal or the superheat brazing temperature in about 2 min, held at brazing temperature for 1 min and cooled to 400° F in about 20 min before being removed from the apparatus. The nominal and superheat brazing temperatures, utilized for each brazing alloy, have been listed in Table 1. The nominal brazing temperature was selected at 90° F (50° C) above the brazing alloy liquidus temperature, while the superheat brazing temperature was 90° F (50° C) above the nominal level.

The design of the test unit was such that the experiments could either be made in a vacuum or under a dried, protective atmosphere, as illustrated in Figs. 1, 3 and 4. For the static dry-hydrogen and helium tests, the apparatus was filled with the particular gas and evacuated to about 0.05–0.07

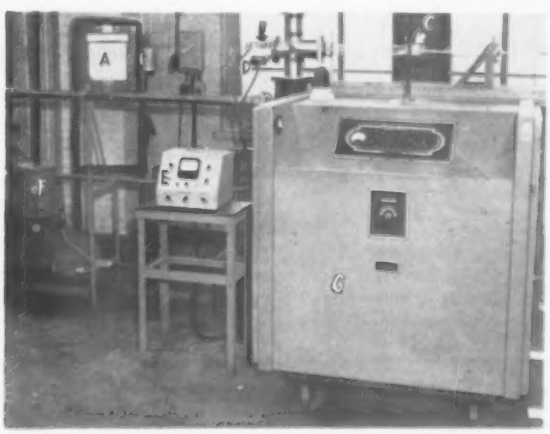


Fig. 3—Wettability-test apparatus, illustrating vacuum equipment. A, multipoint recorder; B, CVC ionization gauge; C, induction coil; D, T.C. gauge; E, model 07-1031-01 NRC vacuum gage; F, Kinney pump size 556; G, 10-kw RF generator

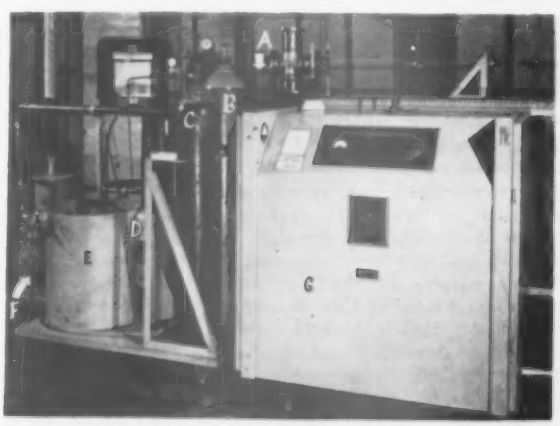


Fig. 4—Wettability-test apparatus, illustrating gas-purifying equipment. A, purified atmosphere inlet; B, argon; C, helium; D, De Oxo unit; E, liquid nitrogen trap; F, purified atmosphere inlet; G, 10-kw RF generator

micron, then twice-filled with purified gas and evacuated to one micron, with the test run following the fourth filling operation. In the wettability tests, vacuums of about 0.05–0.07 micron were obtained, while the hydrogen and helium gases were dried to at least −60° F dewpoint.

Superheat wettability tests were conducted in both vacuum (about 0.05 to 0.07 micron) and dry hydrogen (−60° F dewpoint). In the vacuum, superheat tests, AISI 410, AISI 347, and an iron-base, titanium-hardened alloy were brazed with Alloy 1, Alloy 3 and Alloy 6 brazing alloys. For the dry hydrogen, superheat tests, these same base metals were brazed with Alloy 1, Alloy 3, Alloy 6 and Alloy 5. Silver-manganese (Alloy 5) was excluded from the vacuum tests due to excessive vaporization of both elements in this alloy at 1940° F, its superheat brazing temperature.

Actual-size photographs were taken of all the wettability specimens. Measurements of the surface areas covered by the brazing alloys were obtained by tracing the boundaries of the wetted areas shown by the photographs with a compensating polar planimeter.

After the wettability tests had been photographed and measured, transverse microsections through the brazing alloy-base metal intercept regions were prepared. Photographs of the sections were taken at × 50. These photographs were used to measure solidified contact angles between the brazing alloy and the base metal. Finally, the test specimens were examined visually and microscopically for unusual behaviorisms. Structural changes in both the base metals and brazing alloys and actual diffusion mechanisms were not considered in the scope of this report. These reactions had been considered previously.[2]

Results and Discussion

Wetting Reactions at Nominal Brazing Temperatures

The wettability test results are presented in Table 2 and are illustrated in Figs. 5 through 7. Illustrations of some base metal-brazing alloy solidified contact angles are shown in Figs. 8 and 9. In Tables 2 and 3, the test results are grouped according to decreasing relative wetting indexes, while in Table 4, test combinations exhibiting heavy base-metal penetration are given. In Table 5, general trends produced by the base metals, brazing alloys, and environments are separately considered. Of the 90 wettability tests listed in Table 2, surface area coverage ranged from 1.31 sq in. for run W48 (Ni-base, Ti-hardened alloy: Alloy 3: vacuum) to 0.03 sq in. for run W75 (Ni-base, Ti-hardened alloy: Alloy 4: dry hydrogen).

Table 2—Relative "Wetting Indexes" Obtained at Nominal Brazing Temperature

Run	Wetted area, A, sq in.	Solidified contact angle, θ degrees	Wetting index, W. I. = A cos θ	Wettability-test combination		
				Base metal	Brazing alloy	Protective medium
W49	1.26	1.5	1.3	Ni-base, Ti-hardened alloy	Alloy 4	Vacuum
W48	1.31	1.5	1.3	Ni-base, Ti-hardened alloy	Alloy 3	Vacuum
W51	1.30	→ 0	1.3	Ni-base, Ti-hardened alloy	Alloy 6	Vacuum
W52	1.22	→ 0	1.2	Ni-base, Ti-hardened alloy	Alloy 1	Vacuum
W12	1.10	1.5	1.1	AISI 347	Alloy 4	Vacuum
W7	1.02	3.5	1.0	AISI 347	Alloy 6	Vacuum
W53	0.87	2.2	0.9	Co-base alloy	Alloy 1	Vacuum
W10	0.91	6.7	0.9	AISI 347	Alloy 3	Vacuum
W22	0.89	1.2	0.9	Fe-base, Ti-hardened alloy	Alloy 4	Vacuum
W4	0.65	→ 0	0.7	AISI 347	Alloy 2	Vacuum
W56	0.67	1.8	0.7	Co-base alloy	Alloy 4	Vacuum
W20	0.65	8.5	0.6	Fe-base, Ti-hardened alloy	Alloy 2	Vacuum
W55	0.56	1.5	0.6	Co-base alloy	Alloy 3	Vacuum
W114	0.58	0.75	0.6	Co-base alloy	Alloy 1	Dry helium
W116	0.58	5.7	0.6	Co-base alloy	Alloy 3	Dry helium
W35	0.53	2.0	0.5	AISI 410	Alloy 1	Vacuum
W89	0.54	5.2	0.5	Co-base alloy	Alloy 5	Dry hydrogen
W96	0.55	2.0	0.5	AISI 410	Alloy 1	Dry helium
W102	0.55	2.0	0.5	AISI 347	Alloy 1	Dry helium
W117	0.53	2.0	0.5	Co-base alloy	Alloy 4	Dry helium
W30	0.42	2.6	0.4	AISI 347	Alloy 1	Vacuum
W36	0.35	1.3	0.4	AISI 410	Alloy 2	Vacuum
W58	0.45	7.2	0.4	Co-base alloy	Alloy 6	Vacuum
W54	0.39	0.5	0.4	Co-base alloy	Alloy 2	Vacuum
W65	0.44	→ 0	0.4	Fe-base, Ti-hardened alloy	Alloy 6	Vacuum
W84	0.45	4.2	0.4	Co-base alloy	Alloy 1	Dry hydrogen
W85	0.41	3.4	0.4	Co-base alloy	Alloy 2	Dry hydrogen
W87	0.44	→ 0	0.4	Co-base alloy	Alloy 4	Dry hydrogen
W95	0.36	→ 0	0.4	Fe-base, Ti-hardened alloy	Alloy 6	Dry hydrogen
W119	0.36	→ 0	0.4	Co-base alloy	Alloy 6	Dry helium
W47	0.42	2.2	0.4	Ni-base, Ti-hardened	Alloy 2	Vacuum
W64	0.35	1.5	0.3	AISI 410	Alloy 4	Vacuum
W86	0.31	→ 0	0.3	Co-base alloy	Alloy 3	Dry hydrogen
W81	0.28	3.6	0.3	AISI 347	Alloy 4	Dry hydrogen
W71	0.29	7.5	0.3	AISI 410	Alloy 5	Dry hydrogen
W20A	0.31	3.2	0.3	Fe-base, Ti-hardened alloy	Alloy 3	Vacuum
W88	0.34	→ 0	0.3	Co-base alloy	Alloy 6	Dry hydrogen
W115	0.29	5.5	0.3	Co-base alloy	Alloy 2	Dry helium
W105	0.32	3.5	0.3	AISI 347	Alloy 4	Dry helium
W123	0.27	13.5	0.3	Fe-base, Ti-hardened alloy	Alloy 4	Dry helium
W107	0.25	→ 0	0.3	AISI 347	Alloy 6	Dry helium
W17	0.21	1.3	0.2	Fe-base, Ti-hardened alloy	Alloy 1	Vacuum
W46	0.22	13.2	0.2	AISI 410	Alloy 3	Vacuum
W50	0.19	14.0	0.2	Ni-base, Ti-hardened alloy	Alloy 5	Vacuum
W82	0.17	→ 0	0.2	AISI 347	Alloy 6	Dry hydrogen
W66	0.18	12.1	0.2	AISI 410	Alloy 1	Dry hydrogen
W78	0.21	2.5	0.2	AISI 347	Alloy 1	Dry hydrogen
W72	0.19	27.3	0.2	Ni-base, Ti-hardened alloy	Alloy 1	Dry hydrogen
W67	0.21	26.1	0.2	AISI 410	Alloy 2	Dry hydrogen
W79	0.22	5.0	0.2	AISI 347	Alloy 2	Dry hydrogen

The measured solidified contact angles, also presented in Table 2, varied from essentially 0 for twelve runs to 55.5 deg. for run W74 (Ni-base, Ti-hardened alloy: Alloy 3: dry hydrogen). Here, low contact angles may be dependent upon a low

(Listed in Decreasing Order)

Run	Wetted area, A, sq in.	Solidified contact angle, θ degrees	Wetting index W. I. = A cos θ	Wettability-test combination: Base metal	Brazing alloy	Protective medium
W90	0.18	2.0	0.2	Fe-base, Ti-hardened alloy	Alloy 2	Dry hydrogen
W68	0.20	10.5	0.2	AISI 410	Alloy 3	Dry hydrogen
W80	0.23	6.5	0.2	AISI 347	Alloy 3	Dry hydrogen
W69	0.24	6.5	0.2	AISI 410	Alloy 4	Dry hydrogen
W93	0.21	16.5	0.2	Fe-base, Ti-hardened alloy	Alloy 4	Dry hydrogen
W83	0.23	15.5	0.2	AISI 347	Alloy 5	Dry hydrogen
W94	0.23	5.8	0.2	Fe-base, Ti-hardened alloy	Alloy 5	Dry hydrogen
W76	0.18	7.9	0.2	Ni-base, Ti-hardened alloy	Alloy 6	Dry hydrogen
W70	0.20	3.0	0.2	AISI 410	Alloy 6	Dry hydrogen
W97	0.24	9.5	0.2	AISI 410	Alloy 2	Dry helium
W103	0.20	9.2	0.2	AISI 347	Alloy 2	Dry helium
W98	0.21	11.5	0.2	AISI 410	Alloy 3	Dry helium
W104	0.23	4.2	0.2	AISI 347	Alloy 3	Dry helium
W99	0.24	6.3	0.2	AISI 410	Alloy 4	Dry helium
W111	0.29	33.5	0.2	Ni-base, Ti-hardened alloy	Alloy 4	Dry helium
W118	0.19	9.0	0.2	Co-base alloy	Alloy 5	Dry helium
W100	0.20	→ 0	0.2	AISI 410	Alloy 6	Dry helium
W124	0.19	10.0	0.2	Fe-base, Ti-hardened alloy	Alloy 6	Dry helium
W113	0.19	7.5	0.2	Ni-base, Ti-hardened alloy	Alloy 6	Dry helium
W45	0.10	7.0	0.1	AISI 410	Alloy 5	Vacuum
W57	0.12	14.2	0.1	Co-base alloy	Alloy 5	Vacuum
W37	0.15	10.6	0.1	AISI 410	Alloy 6	Vacuum
W91	0.15	17.7	0.1	Fe-base, Ti-hardened alloy	Alloy 1	Dry hydrogen
W92	0.14	11.7	0.1	Fe-base, Ti-hardened alloy	Alloy 3	Dry hydrogen
W77	0.10	5.0	0.1	Ni-base, Ti-hardened alloy	Alloy 5	Dry hydrogen
W121	0.15	15.5	0.1	Fe-base, Ti-hardened alloy	Alloy 2	Dry helium
W109	0.13	22.8	0.1	Ni-base, Ti-hardened alloy	Alloy 2	Dry helium
W122	0.13	21.8	0.1	Fe-base, Ti-hardened alloy	Alloy 3	Dry helium
W110	0.14	8.5	0.1	Ni-base, Ti-hardened alloy	Alloy 3	Dry helium
W106	0.14	23.0	0.1	AISI 347	Alloy 5	Dry helium
W125	0.15	13.7	0.1	Fe-base, Ti-hardened alloy	Alloy 5	Dry helium
W21	0.10	19.5	0.09	Fe-base, Ti-hardened alloy	Alloy 5	Vacuum
W112	0.07	5.8	0.07	Ni-base, Ti-hardened alloy	Alloy 5	Dry helium
W74	0.10	55.5	0.06	Ni-base, Ti-hardened alloy	Alloy 3	Dry hydrogen
W101	0.08	39.5	0.06	AISI 410	Alloy 5	Dry helium
W73	0.07	53.7	0.04	Ni-base, Ti-hardened alloy	Alloy 2	Dry hydrogen
W75	0.03	30.5	0.03	Ni-base, Ti-hardened alloy	Alloy 4	Dry hydrogen
W120		De-wetted	..	Fe-base, Ti-hardened alloy	Alloy 1	Dry helium
W108		De-wetted	..	Ni-base, Ti-hardened alloy	Alloy 1	Dry helium
W31		Brazing alloy vaporized	..	AISI 347	Alloy 5	Vacuum

brazing-alloy surface tension combined in some cases with considerable diffusion and alloying with the base metal, as shown in runs W100 and W47 of Fig. 8. High contact angles must be associated with high brazing-alloy surface tension, high interfacial tensions, and/or oxidized or contaminated base-metal surfaces (Fig. 9, runs W101 and W106).

Discrepancies were noted when the wettability tests were compared, separately, either on the basis of coverage areas or solidified contact angles. Several test combinations having low solidified contact angles did not exhibit good spreading, (Runs W17, W82, W90 and W100), while for another test, a large solidified contact angle was not accompanied by poor spreading (Run W123).

To compensate for these anomalies, a wetting index was established which jointly evaluated wettability on both the amount of spreading and the solidified contact angle obtained for specific test conditions. The wetting index was determined from the equation: W. I. = A cos θ where W. I. = wetting-index value; A = area covered by the brazing alloy, in^2; θ = solidified contact angle. The cosine of θ was selected so that W. I. would become larger as the contact angle approached zero. Small solidified contact angles would not alter the wetting index seriously, but large solidified contact angles would "penalize" the over-all "wetting-index" rating. Using this rating, a large wetting-index value indicated good wettability, since it corresponded to a combination of good surface coverage and a low solidified contact angle. Comparative numerical values obtained for W. I. ranged from 1.3 for Run W48 (Ni-base, Ti-hardened alloy:Alloy 3:vacuum) and Run W49 (Ni-base, Ti-hardened alloy:Alloy 4:vacuum) to 0.03 for Run W75 (Ni-base, Ti-hardened alloy:Alloy 4:dry hydrogen). One test, Run W31 (AISI 347:Alloy 5:vacuum) could not be classified by a W. I. number, due to the complete vaporization of the silver—15% manganese alloy in the high vacuum of this test. An arbitrary rating for the wetting index numbers is as follows:

W. I.	Wettability
0.6 and above	Excellent
0.5	Very good
0.3-0.4	Good
0.2	Fair
0.1	Poor
<0.1	Very poor

Two test combinations produced a "de-wetting" of the liquid brazing alloy and could not be classified by a W. I. value. In these dry helium runs, W120 (Fe-base, Ti-base, Ti-hardened alloy:Alloy 1:dry helium) and W108 (Ni-base, Ti-hardened alloy:Alloy 1:dry helium), the Alloy 1 apparently possessed an extremely low surface tension and rapidly spread over the base-metal surfaces. However, a surface film had formed upon heating each of

the base metals to the brazing temperature of 1980° F. Being unable to penetrate through the film or to react with the base metals, the liquid Alloy 1 retracted upon cooling from the brazing temperature to a lower equilibrium surface energy level and produced the "de-wetting" shown in Figure 7.*

The exact nature of this surface film is not known but it has been tentatively identified by X-ray diffraction techniques as TiO, TiH or TiC, singly, or in combination. It has been produced in varying degrees on titanium-hardened alloys, from a faint yellow film, produced in vacuum, to a purplish-black film produced in dry hydrogen and dry helium. Since it has also been produced in separate experiments conducted without the presence of brazing-alloy powders, it must form primarily by a reaction between the titanium of the base-metal composition and trace contaminators in the protective atmosphere. Should the compound be identified as TiH, dry hydrogen, fluxless brazing of titanium-bearing alloys may not be feasible. By comparing Runs W108 and W120 with W114 of Fig. 7, the effect on wetting of a titanium addition to an alloy may be seen. Excellent wetting by Alloy 1 was obtained on Run W114 (Co-base alloy) in contrast to Runs W108 (Ni-base, Ti-hardened alloy) and W120 (Fe-base, Ti-hardened alloy) in which a titanium-compound surface film caused "de-wetting" of the brazing alloy.

In test run W73 (Ni-base, Ti-hardened alloy:Alloy 2:dry hydrogen) of Figure 6, the liquid brazing alloys did not spread over the base metals during heating to brazing temperature. Here, visible surface contamination of the base metal must have caused a decrease in the base-metal surface energy, so that even incipient spreading could not occur. Consequently, the brazing alloy remained coalesced throughout the duration of this test.

In other tests, contamination was so excessive that the brazing alloys could not even fuse completely. These were Run W74 (Ni-base, Ti-hardened alloy:Alloy 3:dry hydrogen) and Run W75 (Ni-base, Ti-hardened alloy:Alloy 4:dry hydrogen). Surface contamination of the Alloy 4 brazing alloy could only have occurred due to its reaction with trace contaminators in the hydrogen and/or with the titanium-compound surface films which formed on the base metal.

* A sphere possesses the least surface energy for a given volume of liquid.

Table 3—Relative Wetting Indexes Obtained

Base metal	Run	W. I.	Brazing alloy	Protective medium
AISI 410	W35	0.5	Alloy 1	Vacuum
AISI 410	W96	0.5	Alloy 1	Dry helium
AISI 410	W36	0.4	Alloy 2	Vacuum
AISI 410	W64	0.3	Alloy 4	Vacuum
AISI 410	W71	0.3	Alloy 5	Dry hydrogen
AISI 410	W46	0.2	Alloy 3	Vacuum
AISI 410	W66	0.2	Alloy 1	Dry hydrogen
AISI 410	W67	0.2	Alloy 2	Dry hydrogen
AISI 410	W68	0.2	Alloy 3	Dry hydrogen
AISI 410	W69	0.2	Alloy 4	Dry hydrogen
AISI 410	W70	0.2	Alloy 6	Dry hydrogen
AISI 410	W103	0.2	Alloy 2	Dry helium
AISI 410	W98	0.2	Alloy 3	Dry helium
AISI 410	W99	0.2	Alloy 4	Dry helium
AISI 410	W100	0.2	Alloy 6	Dry helium
AISI 410	W45	0.1	Alloy 5	Vacuum
AISI 410	W37	0.1	Alloy 6	Vacuum
AISI 410	W101	0.06	Alloy 5	Dry helium
AISI 347	W12	1.1	Alloy 4	Vacuum
AISI 347	W7	1.0	Alloy 6	Vacuum
AISI 347	W10	0.9	Alloy 3	Vacuum
AISI 347	W4	0.7	Alloy 2	Vacuum
AISI 347	W102	0.5	Alloy 1	Dry helium
AISI 347	W30	0.4	Alloy 1	Vacuum
AISI 347	W81	0.3	Alloy 4	Dry hydrogen
AISI 347	W105	0.3	Alloy 4	Dry helium
AISI 347	W107	0.3	Alloy 6	Dry helium
AISI 347	W82	0.2	Alloy 6	Dry hydrogen
AISI 347	W78	0.2	Alloy 1	Dry hydrogen
AISI 347	W79	0.2	Alloy 2	Dry hydrogen
AISI 347	W80	0.2	Alloy 3	Dry hydrogen
AISI 347	W83	0.2	Alloy 5	Dry hydrogen
AISI 347	W103	0.2	Alloy 2	Dry helium
AISI 347	W104	0.2	Alloy 3	Dry helium
AISI 347	W106	0.1	Alloy 5	Dry helium
AISI 347	W31(vaporized)		Alloy 5	Vacuum
Fe-Base, Ti-hardened Alloy	W22	0.9	Alloy 4	Vacuum
	W20	0.6	Alloy 2	Vacuum
	W65	0.4	Alloy 6	Vacuum
	W95	0.4	Alloy 6	Dry hydrogen
	W20A	0.3	Alloy 3	Vacuum
	W123	0.3	Alloy 4	Dry helium
	W17	0.2	Alloy 1	Vacuum
	W90	0.2	Alloy 2	Dry hydrogen
	W93	0.2	Alloy 4	Dry hydrogen

Table 4—Wettability Tests Exhibiting Visible Base-Metal Alloying at Nominal Brazing Temperature

	Test combination			Depth of penetration, maximum, in.
Run	Base metal	Brazing alloy	Protective medium	
W51	Ni-base, Ti-hardened alloy	Alloy 6	Vacuum	0.0467
W53	Co-base	Alloy 1	Vacuum	0.0380
W73	Ni-base, Ti-hardened alloy	Alloy 2	Dry hydrogen	0.0376
W107	AISI 347	Alloy 6	Dry helium	0.0361
W47	Ni-base, Ti-hardened alloy	Alloy 2	Vacuum	0.0346
W52	Ni-base, Ti-hardened alloy	Alloy 1	Vacuum	0.0333
W65	Fe-base, Ti-hardened alloy	Alloy 6	Vacuum	0.0301
W7	AISI 347	Alloy 6	Vacuum	0.0301
W48	Ni-base, Ti-hardened alloy	Alloy 3	Vacuum	0.0256
W82	AISI 347	Alloy 6	Dry hydrogen	0.0241
W100	AISI 410	Alloy 6	Dry helium	0.0226
W36	AISI 410	Alloy 2	Vacuum	0.0196
W88	Co-base alloy	Alloy 6	Dry hydrogen	0.0181
W95	Fe-base, Ti-hardened alloy	Alloy 6	Dry hydrogen	0.0140
W4	AISI 347	Alloy 2	Vacuum	0.0135

at Nominal Brazing Temperature on the Various Alloys

Base Metal	Run	W.I.	Brazing alloy	Protective medium
	W94	0.2	Alloy 5	Dry hydrogen
	W124	0.2	Alloy 6	Dry hydrogen
	W91	0.1	Alloy 1	Dry hydrogen
	W92	0.1	Alloy 3	Dry hydrogen
	W121	0.1	Alloy 2	Dry helium
	W122	0.1	Alloy 3	Dry helium
	W125	0.1	Alloy 5	Dry helium
	W21	0.0	Alloy 5	Vacuum
	W120 (de-wetted)		Alloy 1	Dry helium
Ni-Base, Ti-hardened Alloy	W49	1.3	Alloy 4	Vacuum
	W48	1.3	Alloy 3	Vacuum
	W51	1.3	Alloy 6	Vacuum
	W52	1.2	Alloy 1	Vacuum
	W47	0.4	Alloy 2	Vacuum
	W50	0.2	Alloy 5	Vacuum
	W72	0.2	Alloy 1	Dry hydrogen
	W76	0.2	Alloy 6	Dry hydrogen
	W111	0.2	Alloy 4	Dry helium
	W113	0.2	Alloy 6	Dry helium
	W77	0.1	Alloy 5	Dry hydrogen
	W109	0.1	Alloy 2	Dry helium
	W110	0.1	Alloy 3	Dry helium
	W112	0.07	Alloy 5	Dry helium
	W74	0.06	Alloy 3	Dry hydrogen
	W73	0.04	Alloy 2	Dry hydrogen
	W75	0.03	Alloy 4	Dry hydrogen
	W108 (de-wetted)		Alloy 1	Dry helium
Co-Base Alloy	W53	0.9	Alloy 1	Vacuum
	W56	0.7	Alloy 4	Vacuum
	W55	0.6	Alloy 3	Vacuum
	W114	0.6	Alloy 1	Dry helium
	W116	0.6	Alloy 3	Dry helium
	W89	0.5	Alloy 5	Dry hydrogen
	W117	0.5	Alloy 4	Dry helium
	W58	0.4	Alloy 6	Vacuum
	W54	0.4	Alloy 2	Vacuum
	W84	0.4	Alloy 1	Dry hydrogen
	W85	0.4	Alloy 2	Dry hydrogen
	W87	0.4	Alloy 4	Dry hydrogen
	W119	0.4	Alloy 6	Dry helium
	W86	0.3	Alloy 3	Dry hydrogen
	W88	0.3	Alloy 6	Dry hydrogen
	W115	0.3	Alloy 2	Dry helium
	W118	0.2	Alloy 5	Dry helium
	W57	0.1	Alloy 5	Vacuum

Table 5—Number of Wettability Tests Occurring at Each Wetting-Index Level (Nominal Brazing Temperature)

		Wetting index rating						
Base metal:	Total tests	0.6 or higher	0.5	0.4–0.3	0.2	0.1	<0.1	Other	% Total W. I. = 0.2 or higher
AISI 410	18	...	2	3	10	2	1	...	83
AISI 347	18	4	1	4	7	1	...	1	90
Fe-base, Ti-hardened alloy	18	2	...	4	5	5	1	1	61
Ni-base, Ti-hardened alloy	18	4	...	1	5	3	4	1	55
Co-base alloy	18	5	2	9	1	1	...	...	94
Brazing alloy:									
Alloy 1	15	3	3	2	4	1	...	2	80
Alloy 2	15	2	...	5	5	2	1	...	80
Alloy 3	15	4	...	2	5	3	1	...	73
Alloy 4	15	4	1	5	4	...	1	...	93
Alloy 5	15	...	1	1	4	5	3	1	40
Alloy 6	15	2	...	6	6	1	...	...	93
Environments:									
Vacuum	30	12	1	8	3	3	1	1	80
Dry hydrogen	30	...	1	8	15	3	3	...	80
Dry helium	30	2	3	5	10	6	2	3	67

Considerable diffusion and alloying by boron-containing brazing Alloys 1, 2 and 6 were observed in sixteen runs listed in Table 4. This behaviorism may be partially attributed to the ability of the boron, in these alloys, to diffuse rapidly along base-metal grain boundaries, thereby facilitating alloying with the base metals. This suggests that base-metal penetration may be restricted by using brazing-alloy compositions which bond, primarily, by forming superficial solid solutions, and are either free from or contain a minimum of elements that may diffuse excessively into the base metal along grain boundaries. The depth of penetration measured in these runs, in which a considerable amount of brazing alloy was in contact with the base metal, varied from 0.0135 to 0.0467 in., as shown in Table 4.

If the brazing of AISI 347 with Alloy 1 in dry hydrogen is considered a workable commercial practice (Run W78 of Fig. 6, where W. I. = 0.2), all those test combinations of comparable, or greater, W. I. values should produce satisfactory wetting of small joints. A consideration of these tests producing fair to excellent wetting (W. I. = 0.2, or greater) showed that the Co-base alloy was most readily wet, while the Ni-base, Ti-hardened alloy was the most difficult base metal to wet (Table 5). By this same comparison, Alloy 6 and Alloy 4 brazing alloys produced the best, and Alloy 5 brazing alloy, the worst wetting results. The relative insolubility of silver in cobalt, nickel and chromium may partially account for the ineffective wetting of the base metals by Alloy 5. Similarly, a vacuum environment of 0.05–0.07 micron, produced the best wetting results and dry helium atmosphere, of minus 60° F dewpoint, the worst.

In Figs. 10 and 11, the superheated wettability tests are illustrated, while in Table 6, wetting-index data obtained from these tests are summarized.

Superheat-wettability data paralleled the nominal brazing-temperature test results. The Co-base alloy was most readily wet in the superheat tests, of the alloys tested, while Fe-base, Ti-hardened alloy was the most difficult base alloy to wet. Wetting by brazing alloys in vacuum was again generally superior to wetting in dry hydrogen. Alloy 6 brazing alloy produced the best over-all wetting, while Alloy 5 brazing alloy again produced the worst over-all wetting on the base alloys tested.

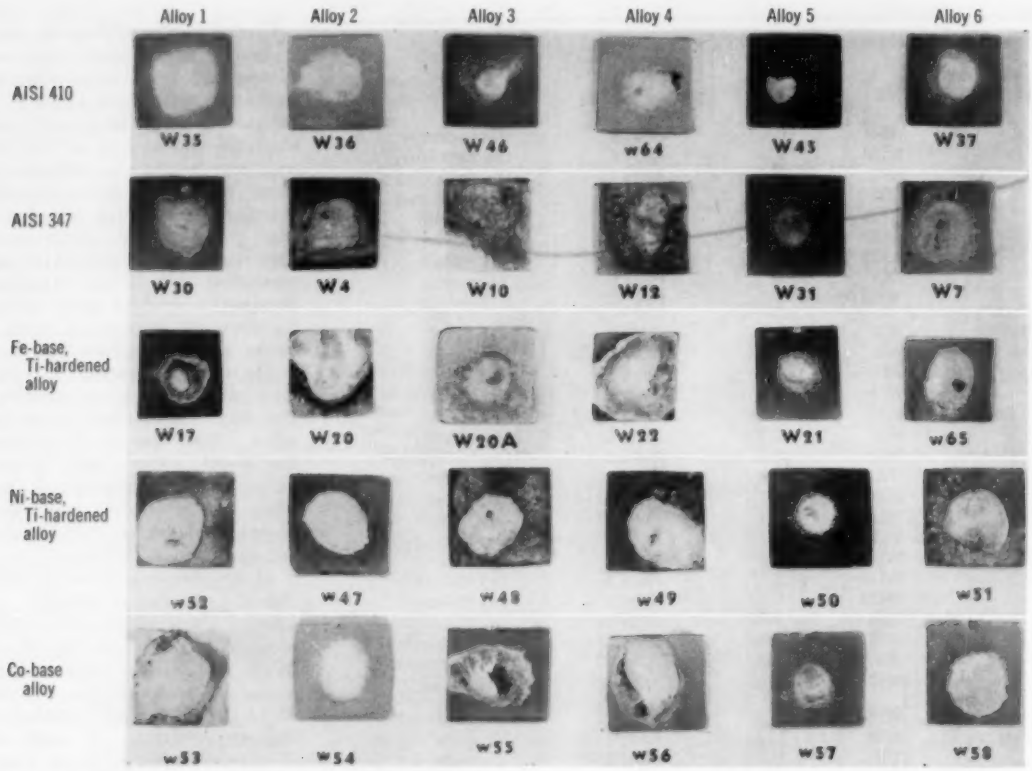


Fig. 5—Vacuum (0.05 micron) wettability tests. × 0.77

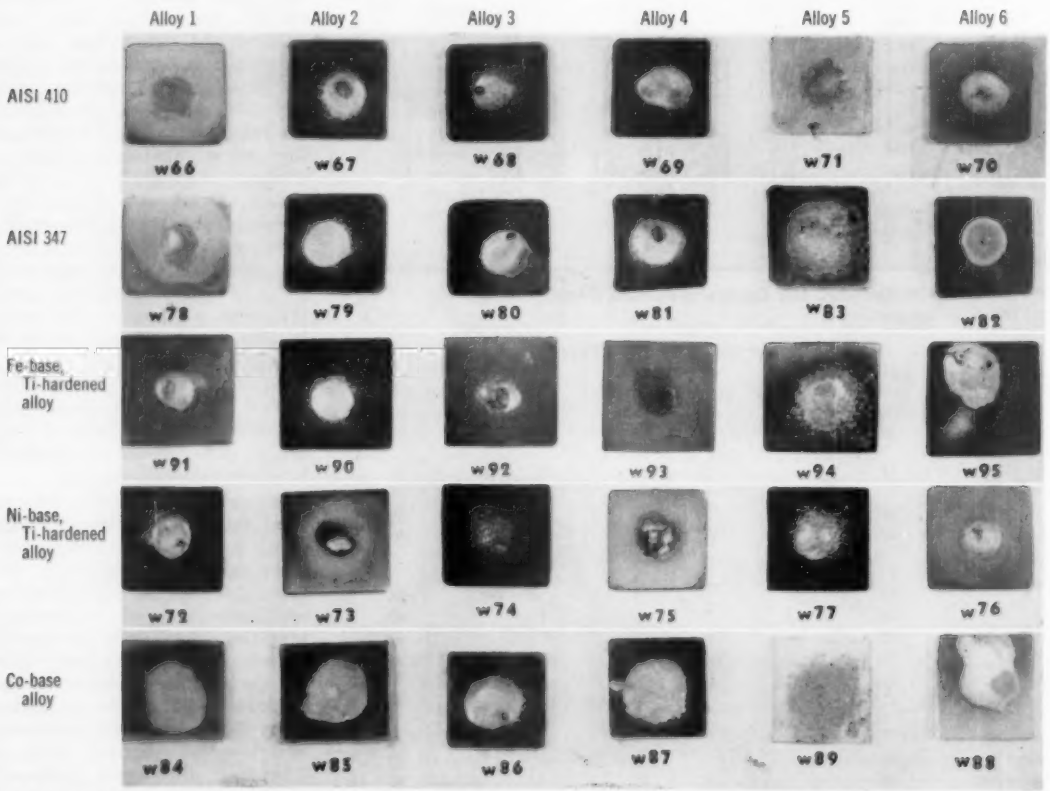


Fig. 6—Dry hydrogen (—50° C dewpoint) wettability tests. × 0.77

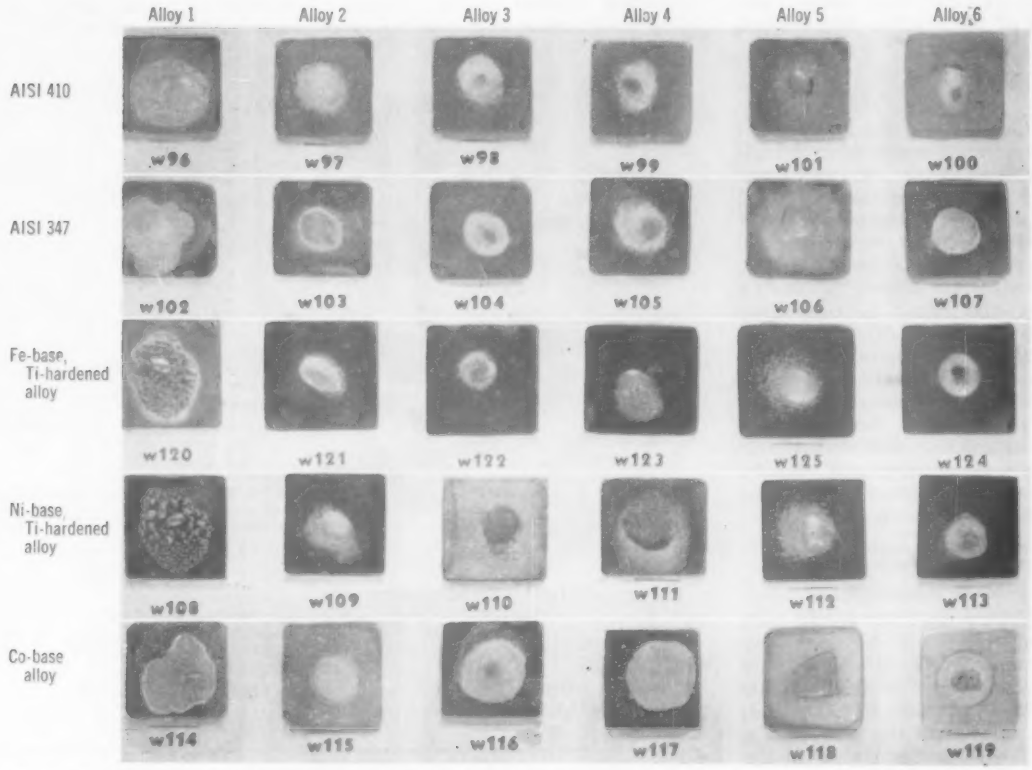


Fig. 7—Dry helium (—50° C dewpoint) wettability tests. × 0.77

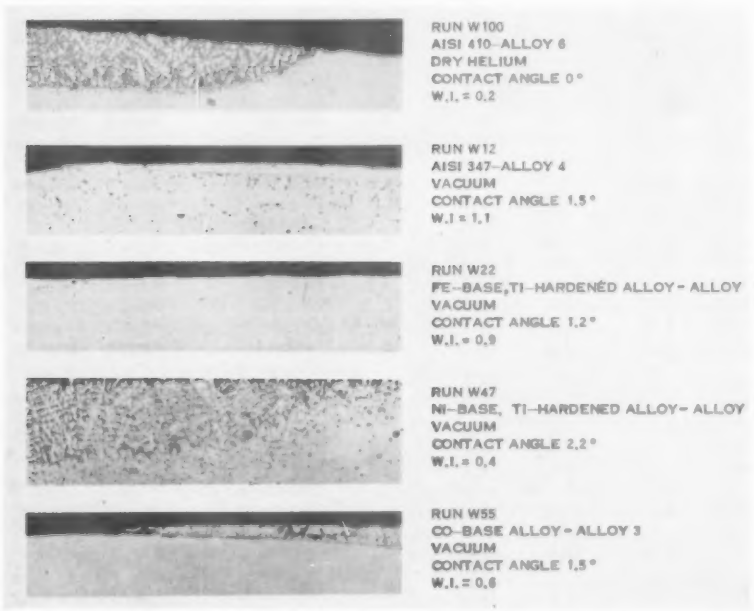


Fig. 8—Wettability tests exhibiting small solidified contact angles. × 50. (Reduced by 1/3 upon reproduction)

One run, W154 (Fe-base, Ti-hardened alloy:Alloy 3:dry hydrogen), could not be classified. In this test, Alloy 3 became severely contaminated, possibly by reaction with the titanium-compound film that formed upon heating the Fe-base, Ti-hardened alloy in dry hydrogen. The contaminated alloy was then neither able to coalesce nor to flow.

Compared with similar wettability tests which have been run at nominal brazing temperatures, superheating reduced wettability (Table 6). At increased brazing temperature, an increased diffusivity into, and alloying with, the base metal by elements in the brazing alloy occurred.

General Summary on Wettability

As previously stated, wettability is the ability of a liquid brazing alloy to spread over a base-metal surface while elements of the brazing alloy superficially diffuse into and alloy with it. A diagram of the forces acting on a liquid droplet of brazing alloy is shown, in two dimensions, in Fig. 12. The vector system for this diagram can be derived from the Dupré equation[4] to yield:

$$\gamma g - s = \gamma l_{-s} + \gamma g - l \cos \theta \quad (1)$$

In the wetting tests, spreading was attained when, upon meltdown of the brazing alloy, the base-metal surface tension or the "spreading tension," $\gamma\ g\text{-}s$, was of greater magnitude than the interfacial ten-

sion, γ *l-s*, and the cosine component of the brazing-alloy surface tension, γ *g-l*, or

$$\gamma g - s > \gamma l - s + \gamma_{g-l} \cos \theta \quad (2)$$

Good spreading by the liquid brazing alloy could result from a high or low base-metal surface energy as long as the conditions of eq 2 would prevail. A clean base-metal surface, a relatively low surface tension in the liquid brazing alloy and a tendency toward superficial alloying between the liquid brazing alloy and the base metal (wetting) would favor the predominance of γ *g-s* and improved wettability.

A low γ *g-s*, or poor spreading, would prevail when the magnitude of the spreading component was less than the interfacial tension and the cosine component of the brazing-alloy surface tension, or,

$$\gamma g - s < \gamma l - s + \gamma g - l \cos \theta \quad (3)$$

A low γ *g-s* would prevail when little alloying tendency would exist between the liquid brazing alloy or contaminated liquid brazing alloy and the solid base metal. Reactive elements, as titanium or aluminum, present in some of the base metals, combine with contaminators in the protective environment to form surface tarnish films. In the wetting tests, excessive reaction of the liquid brazing alloy with these contaminating films on the base-metal surface appeared to increase γ *g-l* and/or γ *l-s*. In some cases, it appeared that γ *g-l* and/or γ *l-s* values produced in this manner were great enough to cause "dewetting," or contraction of the brazing alloy, upon melting, after it had initially spread over and reacted with some of the base-metal surface film. In these instances, γ *g-l* and γ *l-s* tried to contract the droplet into a spherical shape while attempting to attain a minimum equilibrium surface energy level in the liquid.

The increased reactivity with the base metal, which was observed in the microstructure of superheated brazed-joint interfaces, probably effected an increase in interfacial tension γ *l-s*. This change apparently decreased the resultant "spreading tension," γ *g-s*. The surface tension of the liquid brazing alloy may have increased or decreased, after reaction with the base metal at the superheat temperature. However, either an increase or a decrease in the liquid brazing-alloy surface tension was apparently offset by the increase in interfacial tension at the superheat temperature. A decrease in spreading tension of the brazing alloy would result in a concomitant decrease in base metal, surface-area coverage, as found in the

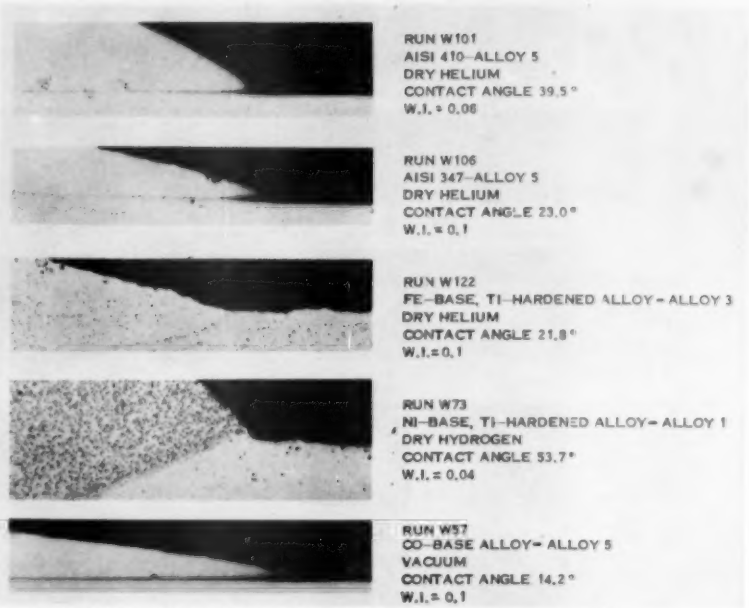


Fig. 9—Wettability tests exhibiting large solidified contact angles. × 50. (Reduced by 1/2 upon reproduction)

Table 6—Relative Wetting Indexes of Superheated Wettability Tests

Run	Wetted area, A sq in.	Solidified contact angle, θ, degrees	Wetting index = A cos	Wetting index, nominal θ temp.	Wettability-test combination: Base alloy	Brazing alloy	Environment
W188	0.38	→0	0.4	0.9	Co-base alloy	Alloy 1	Vacuum
W161	0.37	→0	0.4	0.3	Co-base alloy	Alloy 6	Dry H_2
W179	0.34	4.4	0.3	0.5	AISI 410 alloy	Alloy 1	Vacuum
W159	0.31	4.5	0.3	0.4	Co-base alloy	Alloy 1	Dry H_2
W182	0.27	3.1	0.3	0.2	AISI 410	Alloy 3	Vacuum
W190	0.30	→0	0.3	0.6	Co-base alloy	Alloy 3	Vacuum
W160	0.25	6.0	0.3	0.3	Co-base alloy	Alloy 3	Dry H_2
W183	0.32	3.0	0.3	1.0	AISI 347	Alloy 6	Vacuum
W186	0.28	8.4	0.3	0.4	Fe-base, Ti-hardened alloy	Alloy 6	Vacuum
W189	0.30	1.0	0.3	0.4	Co-base alloy	Alloy 6	Vacuum
W180	0.24	3.0	0.2	0.4	AISI 347	Alloy 1	Vacuum
W156	0.22	5.5	0.2	0.2	AISI 410	Alloy 1	Dry H_2
W163	0.22	2.8	0.2	0.2	AISI 347	Alloy 1	Dry H_2
W184	0.24	5.1	0.2	0.9	AISI 347	Alloy 3	Vacuum
W187	0.21	4.0	0.2	0.3	Fe-base, Ti-hardened alloy	Alloy 3	Vacuum
W164	0.20	5.6	0.2	0.2	AISI 347	Alloy 3	Dry H_2
W162	0.24	→0	0.2	0.5	Co-base alloy	Alloy 5	Dry H_2
W181	0.22	→0	0.2	0.1	AISI 410	Alloy 6	Vacuum
W165	0.21	3.7	0.2	0.2	AISI 347	Alloy 6	Dry H_2
W151	0.16	6.2	0.2	0.4	Fe-base, Ti-hardened alloy	Alloy 6	Dry H_2
W185	0.13	14.8	0.1	0.2	Fe-base, Ti-hardened alloy	Alloy 1	Vacuum
W152	0.10	18.1	0.1	0.1	Fe-base, Ti-hardened alloy	Alloy 1	Dry H_2
W155	0.11	9.1	0.1	0.2	AISI 410	Alloy 3	Dry H_2
W158	0.12	17.0	0.1	0.3	AISI 410	Alloy 5	Dry H_2
W153	0.10	19.6	0.1	0.2	Fe-base, Ti-hardened alloy	Alloy 5	Dry H_2
W157	0.14	8.0	0.1	0.2	AISI 410	Alloy 6	Dry H_2
W166	0.07	16.8	0.07	0.2	AISI 347	Alloy 5	Dry H_2
W154	...	...	...	0.1	Fe-base, Ti-hardened alloy	Alloy 3	Dry H_2

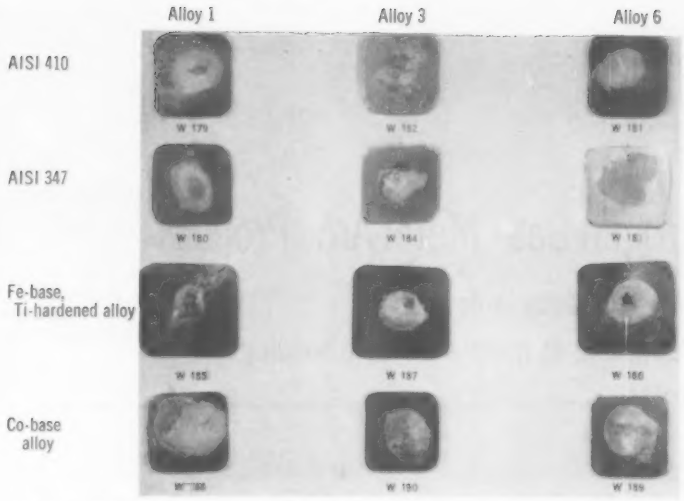


Fig. 10—Wettability tests, superheated in vacuum (~0.05 micron). × 1/2

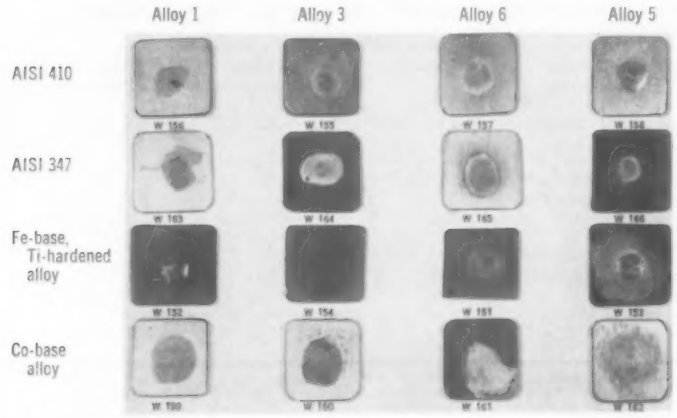


Fig. 11—Wettability tests, superheated in dry hydrogen (—50° C dewpoint). × 1/2

superheat brazing tests.

Conclusions

Wettability-test results were obtained on combinations of five high-temperature alloys, six high-temperature brazing alloys and three atmospheres for nominal and superheat brazing conditions. From these results, numerical wetting-index ratings were determined for each of the wetting-test combinations. A general summary of the mechanisms controlling good and bad wetting action by high-temperature, liquid brazing alloys, on high-temperature base metals, has been presented.

Wetting Reactions at Nominal Brazing Temperature

1. By considering only those wettability tests which produced a satisfactory wettability (wetting index = 0.2, or greater), the following behaviorisms were found:

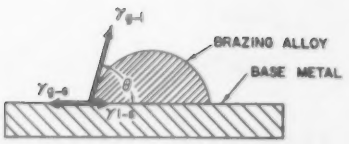
a. Of the base metals, the cobalt-base alloy was most readily wet by the brazing alloys, followed in decreasing order by AISI 347, AISI 410, Fe-base, Ti-hardened alloy, and Ni-base, Ti-hardened alloy.

b. Alloys 4 and 6 produced the best over-all wetting of the base metals followed in order of decreasing effectiveness by Alloy 2, Alloy 1, Alloy 3 and Alloy 5.

c. A vacuum of 0.05–0.07 micron produced the best environmental condition for wetting. Dry hydrogen and dry helium were, respectively, less effective.

2. The titanium present in the iron and nickel-base alloys reacted with hydrogen, oxygen or carbon in the protective media, to form a surface compound film which retarded wettability.

3. Considerable diffusion and base-metal alloying were observed when using Alloy 1, Alloy 2 and Alloy 6 brazing alloys. This was partially attributed to the ability of the boron, contained in these alloys, to penetrate intragranularly into the base metals.



γ_{g-l} = SURFACE TENSION OF THE LIQUID BRAZING ALLOY.

γ_{l-s} = INTERFACIAL TENSION, LIQUID BRAZING ALLOY TO SOLID BASE METAL.

γ_{g-s} = SURFACE TENSION OF SOLID SURFACE.

θ = CONTACT ANGLE $<90°$, WHEN WETTING CAN OCCUR.

$\gamma_{g-s} = \gamma_{l-s} + \gamma_{g-l} \cos\theta$

Fig. 12—Force system affecting wettability, in two dimensions

Wetting Reactions at Superheat Brazing Temperature

1. Superheating different types of high-temperature brazing alloys generally produced a decrease in the wettability of various types of high-temperature alloys, both in vacuum and in dry-hydrogen environments.

2. Decreased wettability was probably caused by an increase in liquid brazing alloy—solid base-metal interfacial tension at superheat brazing temperature.

3. Increased interfacial tension reflected greater diffusivity and reactivity by elements in the brazing alloy with the base metal at the superheat brazing temperature.

4. Wetting indexes obtained at superheat brazing temperature paralleled those obtained at a nominal brazing temperature, but at a lower order of magnitude:

a. Alloy 6 brazing alloy produced the best over-all wetting of the base metals tested.

b. The cobalt-base alloy was most readily wet by the brazing alloys tested, while the Fe-base, Ti-hardened alloy was the most difficult base metal to wet.

c. Wettability results obtained in vacuum were superior to those obtained in dry hydrogen at superheat-brazing temperatures.

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Aluminum Welding Using the Inert-Plus-Nitrogen-Gas Metal-Arc Process

Special gas-shielded metal-arc welding technique is developed to reduce the cost of aluminum welding and to make aluminum welding less dependent upon supply of inert gas

BY GEORGE ALLEN

ABSTRACT. To reduce the cost of aluminum welding and make aluminum welding less dependent upon the supply of inert gas, a special technique of gas-shielded metal-arc welding was developed. This technique uses approximately five cubic feet per hour (cfh) of inert gas through the contact tube with approximately fifteen cfh of nitrogen through the regular gas nozzle of a gas-shielded metal-arc gun.* A substantial saving in inert-gas consumption and cost results.

This process can be used for welding EC† aluminum and aluminum alloys containing little or no magnesium, producing welds satisfactory for many noncode applications. Typical applications include: (*a*) welding electrical bus bar and (*b*) welding aluminum alloy 3003 with 1100 alloy filler wire and (*c*) welding aluminum alloy 6061 with 4043 alloy filler wire.

Table 1—Test Series and Materials Used in the Investigation of Welding Aluminum with the Inert-Plus-Nitrogen-Gas Metal-Arc Process[a]

Test material and purposes	Base metal — Thickness, in.	Base metal — Alloy	Filler — Diameter, in.	Filler — Alloy	No. of weldments	Reference tables
Welding of EC aluminum at the laboratory	1 1/4	EC	3/32	1100	56	2, 3 4, 6
Operator qualification tests on welding EC aluminum	1 1/4	EC	3/32	1100	35	5, 6
Welding various aluminum plate-filler alloy combinations	1	3003	1/16	1100	4	7
	1/2	6061	1/16	4043	5	8
	1/2	6061	1/16	5356	4	9
	1/2	5083	1/16	5356	4	10
	1/2	5086	1/16	5356	4	11

[a] Typical conditions used for the welding of EC aluminum with 1/16-in. diam 1100 filler were 27–31 v and 290–320 amp. Typical conditions used for the welding of alloys 3003, 6061, 5083 and 5086 with 1/16-in. diam filler were 29–31 v and 230 to 250 amp. Reverse-polarity direct current used in all cases.

Introduction

The purpose of this investigation was to reduce the cost of shielding gas in inert-gas-shielded metal-arc welding of aluminum. Either reducing the amount of inert gas used or substitution of less expensive gases such as nitrogen or carbon dioxide appeared logical areas to investigate. An argon shortage precipitated sudden action. Accordingly, a crash research program was conducted to investigate these possibilities. One phase of the investigation was to study various means of reducing the inert-gas flow during gas-shielded metal-arc welding of aluminum. Studies were also made to increase the shielding-gas efficiency by means of various dual-nozzle designs.

Simultaneously, nitrogen and carbon dioxide were tried as direct substitutes for argon on aluminum welding. Carbon dioxide was unsuccessful, producing extremely drossy, dirty welds. Nitrogen looked more promising, but at this point could not be used as a direct substitute.

In the meantime, on another research project, a technique of welding had been devised wherein various gases such as argon +3% chlorine were passed through the contact tube in addition to the regular shielding gas. It appeared that perhaps the contact-tube technique would work with nitrogen, if argon or helium could be passed through the contact tube to provide an inner core or shield around the arc column and transferring metal.

Tests confirmed that single-pass aluminum welds could be made using 2 to 10 cfh argon or helium in the contact tube with 10 to 20 cfh nitrogen in the regular shielding nozzle. Initially, multipass welds could not be made, because of the formation of an aluminum-nitride film on top of the weld bead which prevented fusion of successive beads. The solution was found to be the use of a very short visible welding arc.

With this technique, a large number of weldments in EC aluminum was fabricated in the laboratory and tested for mechanical and electrical properties. Upon completion of the laboratory work, 35 welders were given a short training course, including operator qualification tests, for welding EC aluminum bus bar by the inert-plus-nitrogen-gas metal-arc welding process. In addition, the welding of aluminum alloys 3003, 6061, 5086 and 5083 was investigated to determine if this low-cost welding process could be applied to these alloys.

Materials and Procedure

Table 1 summarizes the materials and tests used in the investigation of gas metal-arc welding of alu-

GEORGE ALLEN is Research Engineer at the Welding Branch of Kaiser Aluminum & Chemical Corp., Spokane, Wash.

* This process is protected by patent rights of Kaiser Aluminum & Chemical Corp.

† EC aluminum is at least 99.45% pure and widely used for electrical conductor metal.

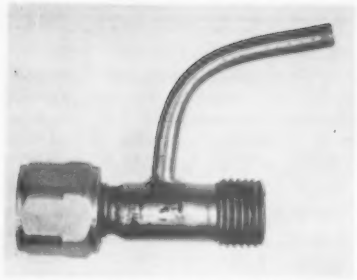


Fig. 1—Adapter for a gas-shielded metal-arc welding gun in order to pass gas through the contact tube

Fig. 2—Gas-shielded metal-arc welding gun adapted for passing gas through the contact tube

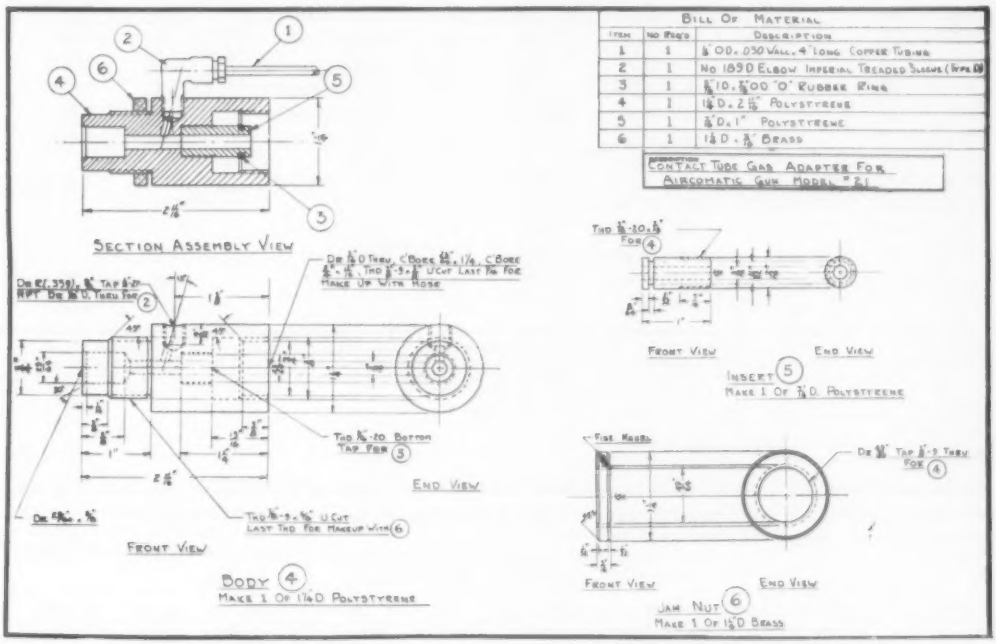

BILL OF MATERIAL
ITEM
NO REQ'D
DESCRIPTION
1 1 ⅜ O.D. .030 WALL 4' LONG COPPER TUBING
2 1 NO 1890 ELBOW IMPERIAL TREADED SLEEVE (TYPE B)
3 1 ⅜ I.D. ⅝ O.D. "O" RUBBER RING
4 1 1¾ D. 2⅛ POLYSTYRENE
5 1 ⅜ D. 1" POLYSTYRENE
6 1 1¾ D. ⅜ BRASS
CONTACT TUBE GAS ADAPTER FOR AIRCOMATIC GUN MODEL "21"
SECTION ASSEMBLY VIEW
FRONT VIEW
END VIEW
BODY (4)
MAKE 1 OF 1¾D POLYSTYRENE
INSERT (5)
MAKE 1 OF ⅜D. POLYSTYRENE
JAM NUT (6)
MAKE 1 OF 1½D BRASS

Fig. 3—Drawing of adapter suggested for a commercially available gas-shielded metal-arc welding gun

minum with inert-plus-nitrogen-gas as the shielding medium.

A 40- to 45-deg single-bevel joint design was used in all tests made on EC aluminum. A Vee bevel of 70-deg included angle was used in the tests on alloys 3003, 6061, 5083 and 5086.

Modification of Welding Gun

The first step was to adapt a gas-shielded metal-arc hand gun for contact-tube welding. Figure 1 shows the adapter used to convert a manual welding gun for this process. Figure 2 shows the adapter in place so that the inert gas can flow through the contact tube while nitrogen can flow through the regular nozzle of the gun. The regular gas line of the welding machine was connected to a supply of nitrogen gas, and a separate hose went from the adapter to the argon supply.

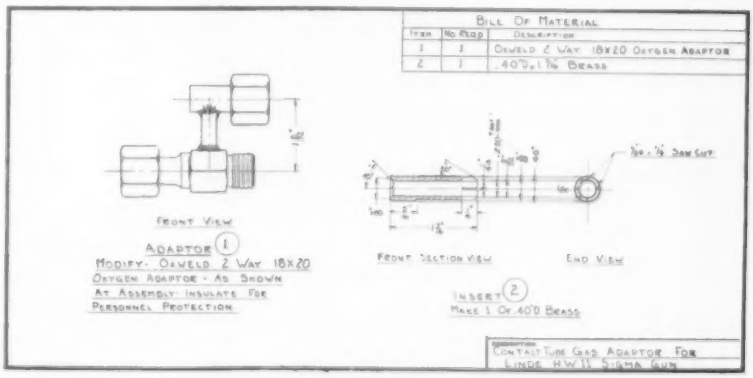

BILL OF MATERIAL
ITEM
NO REQ'D
DESCRIPTION
1 1 ORWELD 2 WAY 18X20 OXYGEN ADAPTOR
2 1 .40"D. x 1⅝ BRASS
FRONT VIEW
ADAPTOR (1)
MODIFY: ORWELD 2 WAY 18X20 OXYGEN ADAPTOR - AS SHOWN
AT ASSEMBLY: INSULATE FOR PERSONNEL PROTECTION
FRONT SECTION VIEW
END VIEW
INSERT (2)
MAKE 1 OF .40"D BRASS
CONTACT TUBE GAS ADAPTOR FOR LINDE HW 11 SIGMA GUN

Fig. 4—Drawing of adapter suggested for a commercially available gas-shielded metal-arc welding gun

Figures 3, 4 and 5 are engineering drawings of adapters suggested for the commercially available welding guns of three different makes.

Variations in Shielding-Gas-Flow Rates

The optimum gas-flow rates were not known. To determine the proper range, the inert-gas flow

Table 2—Welding EC Aluminum with Helium-Plus-Nitrogen-Gas Metal-Arc Welding*

Weldment	Gas flow	No. of tensile samples	Tensile strength, psi Min	Max	Avg	Avg yield strength, psi	Average elongation, % in 2 in.	180-Deg ASME bend test (4T diam) Face	Root	Side	Electrical resistance at 20° C in microhms† Across weld	Across base	Radiographic classification of welds‡
L-23	4He + 20N_2	4	11,500	12,000	11,700	5500	51.6	..	..	Sound	6.45	6.06	..
W-38	4He + 20N_2	4	12,000	14,000	12,700	6300	47.3	..	..	Sound	1.64	1.49	C
W-39	4He + 20N_2	4	11,500	14,000	12,600	6600	48.5	..	..	Sound	6.72	6.08	C+
Z-39	4He + 20N_2	4	11,000	11,500	11,300	4800	50.4	..	..	Sound	6.56	6.09	C
W-46	8He + 10N_2	3	11,000	12,000	11,500	4800	21.0	..	..	Sound	..	..	C—
W-48	5He + 12N_2	2	12,000	13,000	12,500	7000	52.0	..	..	Sound	2.54§	2.56	B—
L-32	8He + 10N_2	3	11,500	12,000	11,800	5800	54.8	..	..	Sound	..	..	B
L-33	8He + 10N_2	3	11,500	13,500	12,300	5700	54.8	..	..	Sound	..	..	B—
Z-48	5He + 15N_2	2	12,000	12,500	12,100	6400	51.7	..	..	Sound	2.63§	2.68	C+
Z-57	5He + 15N_2	2	11,500	11,500	11,500	5200	39.5	Sound	Sound	..	2.41	2.22	C
Z-58	5He + 15N_2	2	11,500	11,500	11,500	5700	56.5	Sound	Sound	..	2.39	2.20	C+
L-40	5He + 15N_2	2	11,500	12,000	11,700	5400	59.0	Sound	Sound	..	2.40§	2.41	A—
L-53	5He + 15N_2	2	11,500	11,500	11,500	5900	59.0	Sound	Sound	..	2.40	2.20	C—
W-58	5He + 15N_2	2	13,500	14,000	13,700	7100	50.0	Sound	Sound	..	2.37	2.20	Below C
W-59	5He + 15N_2	2	11,500	13,000	12,500	6400	51.3	170° (s. c)	Sound	..	2.45	2.26	Below C
W-60	5He + 15N_2	2	11,500	12,000	11,700	6000	56.7	Sound	Sound	..	2.29	2.20	C—
L-70	5He + 15N_2	2	11,500	13,500	12,500	6300	49.0	Sound	..	..	2.34	2.21	B+
L-73	5He + 15N_2	2	12,500	13,500	12,900	5800	45.7	Sound	..	..	2.36	2.21	B—
Z-72	5He + 15N_2	2	13,500	14,000	13,700	7100	45.0	Sound	..	..	2.32	2.20	C+
Z-73	5He + 15N_2	2	10,500	10,500	10,500	5900	47.5	Sound	..	..	2.42	2.21	C
	Total	51 Avg	11,700	12,500	12,100	6000	49.6				3.22‖	2.99‖	

* A single-bevel joint design, 1100 alloy A-finish filler wire was used for all welding of the 1¼-in. thick EC bus bar.
† The specimens for this test were not all of the same cross-sectional area which accounts for the range in electrical resistance between specimens. Weld beads were removed unless noted by footnote §. With the bead on, the cross section of the weld is approximately 10% greater than the bus. Therefore, the electrical resistance through the welds above will be approximately equal to that of the bus.
‡ Radiographic classification according to the Naval Radiographic Standards for Aluminum Welding.
§ Weld beads left on.
‖ Welds with beads off average 7.7% higher than equivalent base metal.

Table 3—Welding EC Aluminum with Inert (75% Helium + 25% Argon)-Plus-Nitrogen-Gas Metal-Arc Welding*

Weldment	Gas flow	No. of tensile samples	Tensile strength, psi Min	Max	Avg	Avg yield strength, psi	Average elongation, % in 2 in.	180-Deg ASME bend test (4T diam) Face	Root	Side	Electrical resistance at 20° C in microhms† Across weld	Across base	Radiographic classification of welds‡
L-22	4-#75 + 20N_2	4	11,500	12,500	12,000	6200	52.7	..	..	Sound	6.44	6.06	B
W-40	4-#75 + 20N_2	4	11,000	11,500	11,300	5300	53.0	..	..	Sound	6.65	6.04	C
Z-37	4-#75 + 20N_2	4	12,000	12,500	11,900	5600	48.3	..	..	Sound	6.55	6.06	C
L-28	8-#75 + 10N_2	3	11,500	12,000	11,600	5300	47.5	..	..	Sound	..	..	B
L-29	8-#75 + 10N_2	3	12,000	12,500	12,100	5400	54.5	..	..	Sound	6.80	6.36	B
Z-43	50#75 + 30N_2	3	10,000	12,000	11,000	5000	32.8	..	..	Sound	..	..	Below C—
W-41	6-#75 + 10N_2	3	10,000	11,000	10,200	4800	16.7	..	..	Sound	6.83	6.38	B
L-39	5-#75 + 15N_2	2	12,000	13,000	12,600	6700	51.2	..	..	Sound	2.58§	2.72	C+
Z-49	5-#75 + 15N_2	2	11,500	12,500	12,100	6200	55.5	..	..	Sound	2.87§	2.74	C
W-49	5-#75 + 15N_2	2	12,000	13,000	12,600	6000	34.0	..	..	Sound	2.56§	2.58	C—
W-61	5-#75 + 15N_2	2	11,500	13,000	12,400	7600	50.7	Sound	Sound	..	2.38	2.20	C
W-62	5-#75 + 15N_2	2	11,500	11,500	11,500	6000	57.0	Sound	Sound	..	2.38	2.21	C—
W-53	5-#75 + 15N_2	2	12,000	12,500	12,200	6100	50.0	150 deg (s. c.)	Sound	..	2.39	2.19	C+
L-71	5-#75 + 15N_2	2	13,000	13,500	13,300	6700	47.5	Sound	..	..	2.30	2.19	B
L-72	5-#75 + 15N_2	2	11,500	13,500	12,500	5600	55.0	Sound	..	..	2.34	2.20	C
Z-70	5-#75 + 15N_2	2	12,000	12,500	12,200	6200	40.2	Sound	..	..	2.36	2.19	C+
Z-71	5-#75 + 15N_2	2	10,000	13,500	11,800	5900	41.0	Sound	..	..	2.35	2.20	C
	Total	44 Avg	11,500	12,500	11,900	6000	45.2				4.15‖	3.86‖	

* A single-bevel joint design, 1100 alloy A-finish filler wire was used for all welding of the 1¼-in. thick EC bus bar.
† The specimens for this test were not all of the same cross-sectional area which accounts for the range in electrical resistance between specimens. Weld beads were removed unless noted by footnote §. With bead on, the cross section of the weld is approximately 10% greater than the bus. Therefore, the electrical resistance through the welds above will be approximately equal to that of the bus.
‡ Radiographic classification according to the Naval Radiographic Standards for Aluminum Welding.
§ Weld beads left on.
‖ Welds with beads off average 7.5% higher than equivalent base metal.

through the contact tube was varied between 2 and 8 cfh while the nitrogen flow through the regular gas nozzle of the gun was varied between 10 and 20 cfh during the initial part of the program. Later the gas flows were standardized at 5 cfh of inert gas and 15 cfh of nitrogen.

Tests to Study Welding of EC Aluminum

Laboratory Development Tests. Three sets of tests totaling 56 weldments were made to develop and investigate the inert-plus-nitrogen-gas metal-arc process for welding EC aluminum bus bar. One series was made with helium gas down the contact tube as reported in Table 2. A second series was made with a gas mixture of 75% helium and 25% argon down the contact tube as shown in Table 3. A third series was made with argon gas down the contact tube as outlined in Table 4. All weldments were radiographed and evaluated mechanically and electrically.

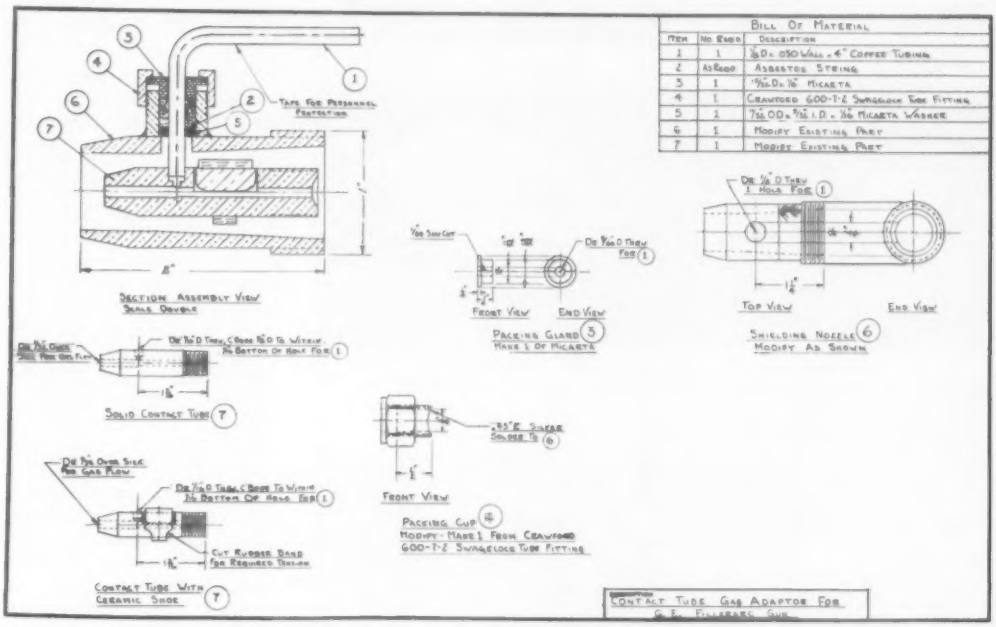

Bill Of Material
Item | No Reqd | Description
1 | 1 | 3/8 OD x .050 Wall x 4" Copper Tubing
2 | As Reqd | Asbestos String
3 | 1 | 1/16 Dia x 1/8" Micarta
4 | 1 | Crawford 600-T-2 Swagelok Tube Fitting
5 | 2 | 7/16 OD x 3/16 I.D. x 1/16 Micarta Washer
6 | 1 | Modify Existing Part
7 | 1 | Modify Existing Part
Tape For Personnel Protection
Section Assembly View
Front View
End View
Packing Gland (5)
Make 1 Of Micarta
Top View
End View
Shielding Nozzle (6)
Modify As Shown
Solid Contact Tube (7)
Front View
Packing Cup (4)
Modify - Make 1 From Crawford
600-T-2 Swagelok Tube Fitting
Contact Tube With
Ceramic Shoe (7)
Contact Tube Gas Adaptor For

Fig. 5—Drawing of adapter suggested for a commercially available gas-shielded metal-arc welding gun

Table 4—Welding EC Aluminum with Argon-Plus-Nitrogen-Gas Metal-Arc Welding*

Weldment	Gas flow	No. of tensile samples	Tensile strength, psi Min	Max	Avg	Avg yield strength, psi	Average elongation, % in 2 in.	180-Deg ASME bend test (4T diam) Face	Root	Side	Electrical resistance at 20° C in microhms† Across weld	Across base	Radiographic classification of welds‡
L-24	4A + 20N_2	4	11,000	11,500	11,300	5700	43.0	..	..	Sound	6.47	6.09	B
Z-38	4A + 20N_2	4	11,500	12,000	11,600	5500	54.5	..	..	Sound	6.35	6.11	..
L-27	2A + 20N_2	3	11,500	13,000	12,100	5800	44.0	..	..	Sound	6.86	6.35	C+
L-30	4A + 20N_2	3	7,000	12,000	10,200	5800	39.5	..	..	Sound	..	..	B
W-43	6A + 15N_2	3	11,500	12,000	11,900	5400	35.5	..	..	Sound	..	..	C+
W-44	6A + 15N_2	3	11,500	12,000	11,700	5100	43.8	..	..	Sound	..	..	B—
Z-51	5A + 15N_2	2	12,500	13,000	12,700	6200	54.0	..	..	Sound	1.75	1.79	B—
Z-59	5A + 15N_2	2	11,500	11,500	11,500	5500	57.0	Sound	Sound	..	2.37	2.19	C
Z-60	5A + 15N_2	2	11,500	12,000	11,800	5300	49.5	Sound	Sound	..	2.32	2.19	C—
Z-61	5A + 15N_2	2	13,000	13,500	13,200	6200	46.5	Sound	Sound	..	2.35	2.20	C—
L-41	5A + 15N_2	2	12,000	13,500	12,700	5800	53.0	..	..	Sound	2.55§	2.64	A—
W-45	5A + 15N_2	3	11,500	13,000	11,800	5100	52.3	..	..	Sound	..	..	B—
W-50	5A + 15N_2	3	11,500	12,000	11,600	5900	57.5	..	..	Sound	2.81§	2.80	C+
W-64	4A + 15N_2	2	11,500	12,500	12,200	6200	56.0	Sound	..	..	2.36	2.20	C+
Z-45	4A + 15N_2	3	11,500	12,500	12,000	5300	39.7	..	..	Sound	..	..	C+
Z-46	4A + 15N_2	3	11,000	12,500	11,800	5300	25.0	..	..	Sound	..	..	B
Z-53	5A + 15N_2	2	12,500	13,500	13,000	6500	54.2	..	..	Sound	1.76§	1.78	A—
L-45	5A + 15N_2	2	11,500	12,000	11,900	5800	53.0	..	..	Sound	1.74§	1.79	A
W-51	3A + 15N_2	2	12,000	13,000	12,500	5600	44.7	..	..	Sound	1.78§	1.77	C
	Total	50	Avg 11,300	12,500	12,000	5700	47.5				3.85‖	3.62‖	

* A single-bevel joint design, 1100 alloy A-finish filler wire was used for all welding of the 1¼-in. thick EC bus bar.

† The specimens for this test were not all of the same cross-sectional area which accounts for range in electrical resistance between specimens. Weld beads were removed unless noted by footnote §. With the bead on, the cross section of the weld is approximately 10% greater than the bus. Therefore, the electrical resistance through the welds above will be approximately equal to that of the bus.

‡ Radiographic classification according to the Naval Radiographic Standards for Aluminum Welding.

§ Weld beads left on.

‖ Welds with beads off average 6.35% higher than equivalent base metal.

All-weld metal specimens were taken from additional welds made in EC aluminum and evaluated for strength, ductility and by metallographic examination.

Welds in EC aluminum were tested for corrosion susceptibility in a 6% NaCl solution for a period of eight months. The specimens were inspected periodically during the test period.

In addition to the electrical-resistance measurements made on all EC test weldments, electrical-conductivity measurements were made on all-weld metal specimens taken from other EC welds made by the inert-plus-nitrogen-gas metal-arc process.

Operator Qualifications. Upon completion of the laboratory work, 35 welders in the field were put through a short training period. Each then fabricated one operator qualification weldment with the inert-plus-nitrogen-gas metal-arc process. Argon was used as the contact-tube gas. These test plates were radiographed and then evaluated mechanically and electrically. Further details are shown in Table 5. Table 6 summarizes the laboratory and qualification test work done on welding EC aluminum.

Tests to Study Welding of Various Aluminum Alloys

The successful field application of the inert-plus-nitrogen-gas metal-arc process to EC aluminum raised the question of whether the process could be used for welding aluminum alloys. Accordingly, weldments using 3003 plate with 1100 filler wire and 6061 plate with 4043 filler wire were made. Subsequently, weldments using 6061, 5083 and 5086 alloys with 5356 filler wire were made. Welding tests were made with helium through the contact tube and nitrogen through the regular nozzle. Details as to the number of weldments, etc., are shown in Tables 7, 8, 9, 10 and 11.

Results and Discussion

Welding EC Aluminum

Tests results of weldments made by this process in EC aluminum are shown in Tables 2 to 5. A summary of these test results is shown in Table 6.

All of the weld specimens in EC aluminum broke in the base metal as illustrated in Fig. 6, except a few which showed evidence of poor welding technique. Table 12 compares the average mechanical properties of EC weldments made with inert-plus-nitrogen-gas metal-arc process to weldments made with argon shielding gas only.

Test results indicate welds made by this process have satisfactory mechanical properties for bus-bar welding.

The electrical resistance across welds made with inert-plus-nitrogen shielding gas (with the weld beads machined off) averaged 8.0% higher than across equivalent lengths of base bus. Normally, the weld bead is left on in bus-bar fabrication, increasing the cross-sectional area by approximately 10% over that of the bus. Therefore, the electrical resistance across a weld made with inert-plus-nitrogen shielding gas, with the bead left on, will be approximately equal

Table 5—Qualification Test Results on EC Aluminum with Argon-Plus-Nitrogen-Gas Metal-Arc Welding*

Welder's No.	Electrical resistance test—% higher than base plate† (weld bead off)	Classification of welder‡	Mechanical properties—Average—Tensile strength, psi	Yield strength, psi	Average elongation, % in 2 in.	Location of fracture	Radiographic qualification of welds§	Remarks re tensile specimens that fractured in the weld metal
406	12.2	U	10,200	4000	55.5	Base metal	A—	.....
414	5.3	A	10,100	7200	52.0	Base metal	A	.....
421	6.0	A	10,800	3800	54.3	Base metal	A	.....
422	10.9	U	11,100	4000	50.5	Base metal	A	.....
441	9.1	C	10,600	3200	39.8	One in weld	B	Folds and porosity
448	8.7	B	11,500	5400	53.0	Base metal	B	.....
449	7.8	B	10,200	4700	54.5	Base metal	B—	.....
450	8.3	B	10,500	4000	50.5	Base metal	A	.....
459	8.3	B	10,100	4200	34.3	One in weld	B	Folds and porosity
465	8.3	B	10,800	4000	61.8	Base metal	B+	.....
467	8.3	B	11,700	6400	53.5	Base metal	B	.....
473	11.4	U	11,000	4100	51.5	Base metal	C—	.....
478	12.2	U	10,200	4800	54.0	Base metal	C—	.....
479	11.5	U	10,400	3600	57.3	Base metal	B	.....
481	8.5	B	10,300	3400	39.5	Base metal	A—	.....
482	5.3	A	11,300	6700	54.8	Base metal	B	.....
484	7.8	B	10,100	4400	53.5	Base metal	A—	.....
485	7.3	A	10,500	3700	55.8	Base metal	B+	.....
492	11.5	U	11,300	5400	49.3	Base metal	C	.....
494	5.6	A	10,400	5300	59.0	Base metal	C	.....
505	8.0	B	12,800	4900	21.8	Base metal	A—	.....
512	7.4	A	10,600	3600	55.5	Base metal	B	.....
513	9.8	C	11,300	4500	49.3	Base metal	B	.....
514	6.7	A	10,900	4600	52.8	Base metal	B—	.....
516	8.7	B	10,800	5500	51.5	Base metal	B—	.....
517	10.5	C	10,900	3400	52.5	Base metal	A—	.....
533	10.7	U	11,600	6100	36.5	Base metal	B—	.....
541	8.8	B	10,200	3500	55.3	Base metal	B	.....
545	7.3	A	10,300	4600	52.8	Base metal	B—	.....
560	11.8	U	10,200	5300	52.8	Base metal	C	.....
567	9.1	C	10,800	4600	52.3	Base metal	B+	.....
584	6.5	A	11,100	7000	52.0	Base metal	B	.....
598	13.5	U	10,000	4900	33.0	One in weld	B	Folds and porosity
614	8.9	B	10,300	3500	51.0	Base metal	A—	.....
615	9.8	C	11,100	3500	51.0	Base metal	A—	.....
	8.9		10,700	4600	48.8			

* Each welder's test plate was sectioned to give two electrical, two tensile, one side bend and one stress-corrosion samples. The stress-corrosion results so far are good and the tests are continuing. All side-bend samples but one passed the 180-deg ASME (4T diam) bend test without showing signs of cracks. Sample No. 545 passed but had a slight edge crack due to a lack of fusion at that point.

† In bus-bar welding, the weld bead is left on so that the weld cross section is usually 10% greater than the base plate.

‡ Our qualification standard was based only on the electrical test results with weld beads machined off. The limits were arbitrarily set. Below 7.5%, A classification; 7.5–9.0%, B classification; 9.0–10.5%, C classification; over 10.5%, U (unsatisfactory).

§ Radiographic classification according to the Naval Radiographic Standards for Aluminum Welding.

to that across an equivalent length of base bus. To substantiate this, 11 specimens were tested with the beads left on (Tables 2 to 4, Footnote 3). The average electrical resistance across these welds was approximately 1% lower than across equivalent lengths of base bus. Therefore, weldments in EC aluminum made by the inert-plus-nitrogen-gas metal-arc process are considered satisfactory for electrical-bus fabrication.

This higher electrical resistance across welds made with inert-plus-nitrogen shielding gas compared with conventional gas metal-arc welds made with inert shielding gas only apparently resulted from aluminum-nitride films which became included in the weld metal during welding. Figure 7 is a macrosection showing the fine, randomly scattered nitride films found in these welds.

The average electrical conductivity of *all-weld metal* taken from inert-plus-nitrogen welds made by various welders on different welding equipment was 52% IACS. This result is based on 48 test specimens. Table 13 compares the conductivity of these welds against the conductivity in EC aluminum, 1100 and 4043 alloys.

A study of the *all-weld metal* samples of these welds in EC plate showed that the nitride films in the weld metal strengthened it but also lowered the ductility slightly. The study also showed that the nitride films are not decomposed in a moist atmosphere. The corrosion studies indicated that welds made in EC aluminum by the inert-plus-nitrogen-gas metal-arc process possess excellent resistance to corrosion.

Welding Various Aluminum Alloys

Alloy 3003 with 1100 Filler. No difficulties were encountered in welding 3003 with 1100 filler using the inert-plus-nitrogen-gas metal-arc welding process.

The results of the weld tests on 3003 alloy using the inert-plus-nitrogen-gas metal-arc process are shown in Table 7. The average tensile and elongation properties of these welds are compared to conventional gas-shielded metal-arc welds with argon shielding gas for the same plate-filler alloy combination in Table 14. The results show that this process will produce satisfactory welds in the 3003 aluminum alloy suitable for many applications. At the present time this process is not recommended for 3003 alloy where code quality welding is required.

Alloy 6061 with 4043 Filler. The results of the weld test on 6061 alloy with 4043 filler alloy using the inert-plus-nitrogen-gas metal-arc welding process are shown in Table 8. The average mechanical properties of these welds are compared to conventional gas-shielded metal-arc welds with argon shielding gas in Table 15.

As shown in Table 15, welds in 6061 with 4043 filler by the inert-plus-nitrogen-gas metal-arc process had less ductility and slightly lower tensile strength than conventional welds. Therefore, this inert-plus-nitrogen-gas metal-arc process may be used for 6061 with 4043 filler only with some sacrifice in weld strength and ductility.

Alloys 6061, 5083 and 5086 with 5356 Filler

The results of weld tests on 6061,

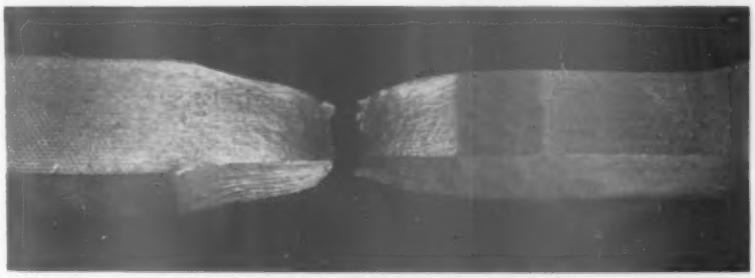


Fig. 6—Typical tensile specimen from a weld in EC aluminum made with the inert-plus-nitrogen-gas metal-arc process. (Note: The fracture usually occurs outside the weld as shown by this specimen)

Fig. 7—Macrosection of a weld made with the inert-plus-nitrogen-gas metal-arc process showing fine, randomly scattered films of aluminum nitride

Table 6—Summary of Mechanical and Electrical Properties of Welds in EC Aluminum Made by the Inert-Plus-Nitrogen-Gas Metal-Arc Process*

Table No.	Shielding gas	No. of weldments†	Average tensile strength, psi	Average yield strength, psi	Average elongation, % in 2 in.	No. of electrical samples	Average higher‡ resistance across weld, %
2	Helium + N_2	20	12,100	6000	49.6	28	7.7
3	Airco 75 + N_2	17	11,900	6000	45.2	24	7.5
4	Argon + N_2	19	12,000	5700	47.5	18	6.35
5	Argon + N_2						
		35	10,700	4600	48.8	70	8.9
		91	11,600§	5500§	48.0§	140	8.0§

* Compiled from: Table 2, Welding EC Aluminum with Helium-Plus-Nitrogen-Gas Metal-Arc Welding; Table 3, Welding EC Aluminum with Inert (75% He + 25% A)-Plus-Nitrogen-Gas Metal-Arc Welding; Table 4, Welding EC Aluminum with Argon-Plus-Nitrogen-Gas Metal-Arc Welding; and Table 5, Qualification Test Results on EC Aluminum with Argon-Plus-Nitrogen-Gas Metal-Arc Welding. Three bend samples developed slight cracks, but all samples passed a 180-deg face, root or side bend.

† Each weldment was sectioned to give 2, 3 or 4 tensile specimens dependent on the width of the weldments. Actual number of specimens are recorded in Tables 2 to 5.

‡ Results of welds tested with beads off. Leaving the bead on increases the cross-sectional area of the weld by approximately 10%.

§ Weighted average according to the number of specimens.

5083 and 5086 aluminum alloys with 5356 alloy filler are shown in Tables 9, 10 and 11, respectively. The average tensile and elongation properties of welds made with the inert-plus-nitrogen-gas metal-arc process in the above plate-filler alloy combinations are compared, in Table 16, to conventional gas metal-arc welds for the same plate-filler alloy combinations. From Table 16 it can be noted that tensile strength and ductility are sacrificed when using the inert-plus-nitrogen-gas metal-arc process to weld the above alloys.

(a) (b)

Fig. 8—Comparison of high-speed photographs of the welding arc in conventional gas-shielded metal-arc welding and inert-plus-nitrogen-gas metal-arc welding. (Note: Digging or submerged characteristic of the arc in the inert-plus nitrogen-gas metal-arc process.) (a) High-speed photograph of inert-gas-shielded metal-arc welding with argon shielding gas. (b) High-speed photograph of welding with the inert-plus-nitrogen-gas metal-arc process

Data in the detailed Tables 9, 10 and 11 show a more serious defect—a wide range between maximum and minimum properties. This wide range in values is believed to result from a burnout of magnesium in the weld metal. The amount of burnout appears to depend on the welding-arc length. The longer the arc, the greater the reaction between magnesium and nitrogen resulting in somewhat lower weld strength.

It was definitely apparent, when welding the high magnesium plate-filler alloy combinations, that there was an increase of spatter, fumes and heat given off as compared to gas-shielded metal-arc welding with inert gas only.

Therefore, for the above reasons, it is not presently recommended that the process using inert-plus-nitrogen shielding gas be used for manual welding of any high-magnesium

Table 7—Welding 3003 Aluminum Alloy with 1100 Filler Alloy Using the Inert-Plus-Nitrogen-Gas Metal-Arc Process*

Weldment No.	Tensile strength, psi Min	Max	Avg	Average elongation, % in 2 in.	180-deg ASME bend test Face	Root	Side	Radiographic classification†
C14-16	15,500	16,000	15,900	26.8	Sound	Sound	Sound	B—
C14-17	15,000	15,500	15,200	25.2	Cracked at 110 deg but passed 180 deg	Cracked at 110 deg but passed 180 deg	Cracked at 110 deg but passed 180 deg	B
C14-18	15,000	15,500	15,300	51.2	Sound	Sound	Cracked at 90 deg, fractured at 180 deg. Cause: large void	B—
C14-19	16,000	16,500	16,100	36.2	Sound	Sound	Sound	C
Avg	15,500	15,800	15,600	34.8				
Typical tensile and elongation properties of 3003 with 1100 filler, conventionally gas-shielded metal-arc welded using argon shielding gas only								
			14,000 to 15,000	30				

* A beveled-joint design of 70-deg included angle was used for welding the 1-in. thick 3003 plate. The gas flows used were 5 cfh He through the contact tube plus 15 cfh N_2 through the regular gun nozzle. Three tensile, one face, one root and one side bend specimens were tested from each weldment.
† Radiographic classification according to the Naval Radiographic Standards for Aluminum Welding.

Table 8—Welding 6061 Aluminum Alloy with 4043 Filler Alloy Using the Inert-Plus-Nitrogen-Gas Metal-Arc Process*

Weldment No.	Tensile strength, psi Min	Max	Avg	Average yield strength, psi	Elongation, % in 2 in.	180-deg bend test (4T diam)† Face, deg	Root, deg	Radiographic classification‡
L-57	24,000	25,000	24,500	16,900	4.0	10	10	Below C
L-62	25,000	25,500	25,200	15,400	4.25	10	5	Below C
L-63	24,000	24,000	24,000	15,100	5.0	20	10	Below C
L-65	19,500	22,000	20,700	13,700	5.25	15	5	Below C
L-62	22,500	24,000	23,200	18,500	3.75	20	5	Below C
Avg	23,000	24,100	25,500	15,900	4.45			
Typical tensile, yield, and elongation properties in 6061 with 4043 filler, conventionally gas-shielded metal-arc welded using argon shielding gas only								
			27,000	17,000	8.5			

* A beveled-joint design of 70-deg included angle was used for welding the ½-in. thick 6061-T6 plate. The gas flows used were 5 cfh He through the contact tube plus 15 cfh N_2 through the regular gun nozzle. Two tensile, one face and one root bend specimens were taken from each weldment.
† This is not the standard ASME bend test for 6061 alloy but a more severe test.
‡ Radiographic classification according to the Naval Radiographic Standards for Aluminum Welding.

plate-filler alloy combinations.

Characteristics of Welding with Inert-Plus-Nitrogen-Gas Metal-Arc Process

The welders find it slightly more difficult to weld by this process than conventional gas metal-arc welding until they become accustomed to the short welding arc technique which must be used. Arc stability is affected by the inert gas used down the contact tube. For ease of welding, helium down the contact tube is considered best, helium-argon second and argon third.

The arc in welding with the inert-plus-nitrogen-gas metal-arc process has a digging or submerging characteristic. High-speed photographs of this process and conventional gas-shielded metal-arc welding were taken to illustrate this characteristic.

Table 9—Welding 6061-T6 Aluminum Alloy with 5356 Filler Alloy Using the Inert-Plus-Nitrogen-Gas Metal-Arc Process*

Weldment No.	Tensile strength, psi Min	Max	Avg	Average elongation, % in 2 in.	180-deg ASME bend test Face	Root	Face	Radiographic classification†
C14-20	27,500	31,000	29,500	10.1	Sound	Sound	Sound	B—
C14-21	23,000	30,000	27,000	7.4	Sound	Sound	Sound	C+
C14-22	24,000	29,000	27,400	7.1	Sound	Sound	Sound	B—
C14-23	25,000	29,000	27,600	8.0	Sound	Sound	Sound	C+
Avg	24,900	29,900	27,800	8.15				
Typical tensile and elongation properties in 6061 with 5356 filler, conventionally gas-shielded metal-arc welded using argon shielding gas only			29,000	11.0				

* A beveled-joint design of 70-deg included angle was used for welding the ½-in. thick 6061-T6 plate. The gas flows used were 5 cfh He through the contact tube plus 15 cfh N_2 through the regular gun nozzle. Four tensile, two face and one root bend specimens were tested from each weldment.

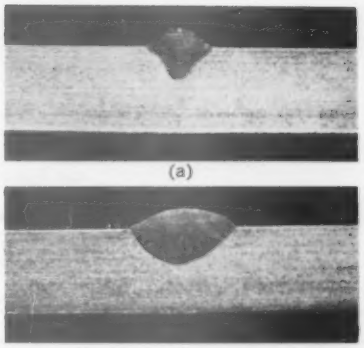
† Radiographic classification according to the Naval Radiographic Standards for Aluminum Welding

Table 10—Welding 5083 Aluminum Alloy with 5356 Filler Alloy Using the Inert-Plus-Nitrogen-Gas Metal-Arc Process*

Weldment No.	Tensile strength, psi Min	Max	Avg	Average elongation, % in 2 in.	180-deg ASME bend test Face	Root	Face	Radiographic classification†
C14-24	38,000	42,000	40,000	12.8	Crack at 70 deg; failed at 90 deg	Crack at 70 deg; failed at 90 deg	Crack at 70 deg; failed at 90 deg	B—
C14-25	30,000	40,500	38,000	10.1	Crack at 70 deg; failed at 90 deg	Crack at 70 deg; failed at 90 deg	Crack at 70 deg; failed at 90 deg	B
C14-26	39,500	42,000	40,800	13.1	Crack at 70 deg; failed at 90 deg	Crack at 70 deg; failed at 90 deg	Crack at 70 deg; failed at 90 deg	C
C14-27	23,500	34,500	31,600	8.0	Crack at 70 deg; failed at 90 deg	Crack at 70 deg; failed at 90 deg	Crack at 50 deg; failed at 70 deg	B—
Avg	34,200	39,699	37,600	11.0				
Typical tensile and elongation properties in 5083 with 5356 filler, conventionally gas-shielded metal-arc welded using argon shielding gas only			40,000	16.0				

* A beveled-joint design of 70-deg included angle was used for welding the ½-in. thick 5083-H113 plate. The gas flows used were 5 cfh He through the contact tube plus 15 cfh N_2 through the regular gun nozzle. Four tensile, two face and one root bend specimens were tested from each weldment.

† Radiographic classification according to the Naval Radiographic Standards for Aluminum Welding.



(a)

(b)

Fig 9—Comparison of weld bead cross section made by inert-gas metal-arc welding and inert-plus-nitrogen-gas metal-arc welding

(Note the greater metal deposition of wider penetration of inert-plus nitrogen-gas metal-arc welding compared to conventional inert-gas metal-arc welding.)

(a) Cross section of a weld bead made at 255 amperes by conventional inert-gas metal-arc welding

(b) Cross-section of a weld bead made at 255 amperes by the inert-plus-nitrogen-gas metal-arc process

Comparative single-frame photographs of the two processes are shown in Fig. 8. This digging characteristic makes welding with inert-plus-nitrogen shielding gas unsuitable for welding thin aluminum material.

Comparative photographs of transverse macrosections of weld beads made by the two processes are shown in Fig. 9. This figure shows the increased penetration and weld-metal deposition of the inert-plus-nitrogen-gas metal-arc process compared to conventional gas-shielded metal-arc welding.

Savings with the Inert-Plus-Nitrogen-Gas Metal-Arc Process

An estimate of potential savings which a fabricator can expect by use of this process must be based on how the fabricator had previously been welding, i.e., his average gas consumption and his cost per cubic foot of inert gas.

For example, one fabricator reported an average gas consumption of over 50 cfh for welding and the cost of gas as slightly above $0.10 per cubic foot. For this fabricator the savings would be at least:

Gas cost for conventional gas-shielded metal-arc process ($50 \times \$0.10$) = $5.00 per arc hour

Inert-plus-nitrogen-gas metal-arc process

5 cfh or argon at $0.10	=	$0.50	
15 cfh of nitrogen at $0.02	=	0.30	
		$0.80	= 0.80 per arc hour
Savings ($5.00 − $0.80)			$4.20 per arc hour

Summary and Conclusions

The inert-plus-nitrogen-gas metal-arc welding process uses 5 cfh of inert gas through the contact tube and 15 cfh of nitrogen through the regular gas nozzle of the welding gun. A short visible welding-arc technique is necessary in multipass welds to prevent heavy formation of infusible aluminum nitride on top of the weld beads.

Test results showed that the mechanical and electrical properties of EC weldments fabricated by this process are satisfactory for aluminum bus-bar welding. The nitride inclusions strengthened the weld metal in EC aluminum weldments but reduced the ductility of the weld metal slightly. The electrical resistance across these welds is approximately equal to that of an equivalent length of base bus, provided the weld-bead reinforcement is left on, as is normally done in bus welding.

An 8-month corrosion test of inert-plus-nitrogen-gas welds in EC aluminum with 1100 filler alloy showed no evidence of significant pitting in the weld metal, heat-affected zone or base plate. There was no evidence of the nitride films decomposing when in contact with moist atmosphere. Therefore, welds made by the inert-plus-nitrogen-gas metal-arc process in EC aluminum appear to have excellent corrosion resistance.

This welding process can also be used satisfactorily on aluminum alloys with little or no magnesium (1100, 3003 and 6061) using filler wire with little or no magnesium as long as high-quality welding is not the prime requisite. With high-magnesium aluminum alloys there is an exothermic reaction between

Table 11—Welding 5086 Aluminum Alloy with 5356 Filler Alloy Using the Inert-Plus-Nitrogen-Gas Metal-Arc Process*

Weldment No.	Tensile strength, psi Min	Max	Avg	Average elongation, % in 2 in.	180-deg ASME bend test Face	Root	Face	Radiographic classification†
C14-28	22,000	38,500	34,300	12.6	Crack at 70 deg; failed at 90 deg	Crack at 70 deg; failed at 90 deg	Crack at 70 deg; failed at 90 deg	C
C14-29	39,000	40,100	39,800	16.6	Crack at 70 deg; failed at 90 deg	Crack at 70 deg; failed at 90 deg	Crack at 70 deg; failed at 90 deg	B—
C14-30	35,000	39,000	37,100	13.3	Crack at 70 deg; failed at 90 deg	Crack at 70 deg; failed at 90 deg	Crack at 70 deg; failed at 90 deg	B—
C14-31	26,000	40,000	32,000	10.3	Crack at 70 deg; failed at 90 deg	Crack at 70 deg; failed at 90 deg	Crack at 70 deg; failed at 90 deg	C
Avg	30,500	39,500	35,500	13.2				

Typical tensile and elongation properties in 5086 with 5356 filler, conventionally gas-shielded metal-arc welded using argon shielding gas only

37,000 17.0

* A beveled-joint design of 70-deg included angle was used for welding the 1/2-in. thick 5086 F plate. The gas flows used were 5 cfh He through the contact tube plus 15 cfh N_2 through the regular gun nozzle. Four tensile, two face and one root bend specimens were tested from each weldment.

† Radiographic classification according to the Naval Radiographic Standards for Aluminum Welding.

Table 12—Comparative Mechanical Properties of EC Aluminum Weldments Made by the Inert-Gas Metal-Arc and the Inert-Plus-Nitrogen-Gas Metal-Arc Processes

Welding process	No. of specimens	Average tensile strength, psi	Average yield strength, psi	Average elongation, % in 2.00 in.	180-deg bend test (4T diam)
Inert-plus-nitrogen-gas metal-arc	215	11,600	5,500	48.0	Sound
Inert-gas-shielded metal-arc (argon shielding gas only)	101	11,800	4,800	57.4	Sound

Table 13—Comparison of Electrical Conductivity

Material	IACS, %
EC bar bus	62
1100 alloy bus	59
1100 alloy weld metal	57–58
Inert-plus-nitrogen weld metal	52
4043 alloy weld metal	42

Table 14—Comparative Mechanical Properties of Weldments in 3003 Alloy Plate-1100 Alloy Filler Made by the Inert-Gas Metal-Arc and the Inert-Plus-Nitrogen-Gas Metal-Arc Processes

Weld process	Average tensile strength, psi	Average elongation, % in 2.00 in.
Inert-plus-nitrogen-gas metal-arc	15,600	34.8
Inert-gas-shielded metal-arc	15,000	30.0

Table 15—Comparative Mechanical Properties of Weldments in 6061 Alloy Plate-4043 Alloy Filler Made by the Inert-Gas Metal-Arc and the Inert-Plus-Nitrogen-Gas Metal-Arc Processes

Weld process	Average tensile strength, psi	Average yield strength, psi	Average elongation, % in 2.00 in.
Inert-plus-nitrogen-gas metal-arc	25,500	15,900	4.45
Inert-gas-shielded metal-arc	27,000	17,000	8.5

Table 16—Comparative Mechanical Properties of Weldments in Aluminum Alloys 6061, 5083 and 5086 with 5356 Alloy Filler Made by the Inert-Gas Metal-Arc and the Inert-Plus-Nitrogen-Gas Metal-Arc Processes

Weld process	Plate	Filler	Average tensile strength, psi	Average elongation, % in 2.00 in.
Welding with inert-plus-nitrogen shielding gas (Table 9)	6061	5356	27,800	8.15
Welding with inert shielding gas only	6061	5356	29,000	11.0
Welding with inert-plus-nitrogen shielding gas (Table 10)	5083	5356	37,600	11.0
Welding with inert shielding gas only	5083	5356	40,000	16.0
Welding with inert-plus-nitrogen shielding gas (Table 11)	5086	5356	35,500	13.2
Welding with inert shielding gas only	5086	5356	37,000	17.0

the nitrogen and magnesium and therefore the inert-plus-nitrogen-gas metal-arc process is not presently recommended for welding these alloys.

The savings of the inert-plus-nitrogen-gas metal-arc process for a fabricator, using an average of 50 cfh argon, will amount to $4.20 per arc-hour. This figure is based on a gas cost of $0.80 per arc-hour for the inert-plus-nitrogen-gas process, as against $5.00 (50 cfh argon at $0.10 per cubic foot) per arc-hour for conventional gas-shielded metal-arc welding with inert shielding gas only.

Acknowledgment

The author expresses his appreciation to all personnel of the Welding Branch and the other assisting branches at the Department of Metallurgical Research, Kaiser Aluminum & Chemical Corp., for their valuable assistance. Special commendation is due K. L. Wills for devising not only the contact-tube welding method, but also the successful short welding-arc technique.

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University Research Conference

The University Research Committee of the Welding Research Council will hold a Conference during the AMERICAN WELDING SOCIETY's 40th Annual Meeting in Chicago on Apr. 8, 1959. This Conference will be held at 8:00 P.M. in the Gold Room of the Hotel Sherman and is being held for University Professors and Research Workers interested in welding research. Directors and managers of research laboratories are also invited to attend. The principal address will be given by Dr. A. B. Kinzel, Vice-President—Research of the Union Carbide Corp. Dr. Kinzel will describe University Research in European countries and Russia as contrasted with research in Universities in the United States. A. R. Lytle, Chairman of the University Research Committee, will also describe the objectives and present activities of the University Research Committee in sponsoring cooperative research projects. He will point out the advantages of sponsoring cooperative research projects in American Universities based not only on the value of the research results but also on the need for training more graduate students in advanced engineering and science, with emphasis on welding.

Research executives from Industry are being invited to this Conference so that they will have an opportunity to exchange ideas with the Professors in an open discussion after Dr. Kinzel's keynote ideas and Mr. Lytle's talk. One of the objectives of this Conference is to enable the University Research Professors to obtain worth-while ideas of what Industry expects from them. Another objective is to inform Industry of the type of research Universities are doing and would like to do in the future in welding and allied fields. Those interested in attending this Conference are invited to do so.

Effects of Martensite, Bainite and Residual Stresses on Fatigue of Welds

Author relates the present knowledge of dislocation theory to some of the questions regarding weld fatigue

BY R. E. KEITH

In approaching the subject of fatigue of welds, one must distinguish between fatigue and the phenomenon of brittle fracture. Under fatigue conditions, stresses are cyclic and are always smaller than those necessary to cause immediate fracture. The cyclic stresses must, however, be large enough to cause plastic flow, without which fatigue failure cannot occur. Plastic flow takes place by the motion of dislocations, and fracture in general is the end result of processes involving dislocations.

During the past several years, a fairly good quantitative theory of dislocations has been developed,[1, 2] and several symposia on fatigue have been held.[3–6] A comprehensive survey of the current state of fatigue theory has appeared.[7] Many problems remain to be solved, but considerable understanding now exists concerning dislocations and their role in fatigue.

This may be an appropriate time, therefore, to attempt to relate our present knowledge of theory to some of the questions regarding weld fatigue. The specific questions are these:

1. Do martensitic and bainitic regions in the weld heat-affected zone act as barriers to dislocation motion, thus initiating fatigue cracks?

2. Do the sharp platelets of martensite and bainite act as internal notches to initiate fatigue cracks?

3. Are residual stresses important in the fatigue of welds?

For purposes of this discussion, let us assume that we have an ideal weld in annealed steel plate which is crack- and inclusion-free, contains no porosity and which has been ground flush with the surface of the plate. Cracks, inclusions, porosity and surface notches are known to be detrimental.

R. E. KEITH is connected with the General Electric Research Laboratory, Schenectady, N. Y.

Martensite and Bainite as Barriers to Dislocations

One popular theory of fracture presupposes that barriers to dislocation motion exist in materials, and that, under the influence of a stress, dislocations pile up against these barriers. The resulting stress concentrations are assumed sufficiently large to initiate cracks. Authorities differ regarding the precise manner in which the crack would form and propagate.

From our present knowledge, however, it appears unlikely that martensite or bainite (or almost anything else) could act as an effective barrier to dislocations. It can be shown from dislocation theory[1] that the stress-concentration factor ahead of a dislocation pile-up is equal to the number of dislocations in the pile-up. Since martensite has a yield stress only two or three times greater than that of annealed steel, it should yield when only a few dislocations have piled up. Bainite should yield even earlier.

On the other hand, calculations from fracture theory (for example, 8) indicate that of the order of 10^3 dislocations must pile up to nucleate a crack. Furthermore, the fact that secondary slip systems are available in the matrix material, on which stress concentrations can be dissipated, makes the existence of pile-ups even more unlikely.

The fracture behavior of cemented carbides may be an instructive case in point. These materials consist of strong, hard carbide particles imbedded in a relatively soft metallic phase, or binder. Gurland[9] has shown that in such materials, containing more than about 20 vol.-% binder, the fracture path always avoids the carbide particles. Instead, the crack prefers to propagate entirely through the binder. The fatigue fracture path in a weld would probably be similar, at least for microstructures containing less than about three-quarters martensite.

In addition to its required mechanical strength, an effective dislocation barrier would have to be extensive in size, or else dislocations could simply climb around it. It is difficult to imagine what such barriers might be, especially in single-crystal specimens (which fatigue properly) and near free surfaces (where most fatigue cracks initiate).

A mechanism of fatigue-crack formation which seems to the author much more likely than the pile-up mechanism is a process involving the coalescence of point-defects, especially lattice vacancies, as a result of cyclic plastic flow. When certain types of dislocations intersect each other during their motion, such point-defects are formed in considerable number.[1, 2] It has been pointed out[10] that continuing cyclic plastic strain alone can result in coalescence of these vacancies into ever-larger clusters. Assistance from thermal agitation may be helpful, but it is not necessary. Thus, this mechanism could account for fatigue even at extremely low temperatures. Ultimately, a sufficient number of large-vacancy clusters will be produced so that fracture takes place under the applied load.

Martensite and Bainite as Stress Concentrators

To suppose that martensite and bainite, because they are acicular in shape, must therefore act as internal notches overlooks the fact that both are mechanically stronger than the annealed matrix. There

is a great deal of difference between this case and the case of a relatively weak inclusion or a void contained in a matrix. The slag inclusion or void carries essentially no load and does constitute a notch. The deleterious influence of such inclusions on fatigue strength of wrought alloy steels has been exhaustively investigated by Cummings, Stulen, and Schulte.[11] Any stress concentrations which exist around the edges of a martensite or bainite platelet, however, will be relieved by plastic flow in the weaker matrix within a very few stress cycles. Thus, there should be no lasting shape effect on fatigue connected with martensite or bainite platelets.

Residual Stresses and Fatigue

There is one basic difference between an internal stress and an externally applied stress. The former is capable of relaxing to a lower value more or less independently of external conditions. Application of small amounts of plastic strain results in almost complete destruction of a pre-existing internal stress system in most materials. This fact is the basis for the well-known finishing processes of roller- and stretch-leveling of sheet, and one uses the same principle when he straightens a wire by clamping one end and exerting a sudden force on the other end.

Under cyclic-loading conditions, and especially in cases where some plastic flow occurs throughout the cross section of the part rather than only near the surface, residual stresses are not likely to be important. When the applied stress is not sufficiently large to cause any plastic flow, the residual stresses may remain, but there is no fatigue failure. If the applied stress is sufficiently large that, added to the residual stress, it results in immediate failure, we are no longer talking about the case of fatigue.

Whether significant fatigue damage occurs before residual stresses have relaxed to safe values depends on the individual case, however. In quenched-and-tempered steels, especially the ultra-high-strength steels, for example, the fatigue limit is as little as one-half the engineering yield stress. It has been shown that very small amounts of plastic deformation also occur in these materials at stresses far below the yield stress.[12, 13] Residual stresses, on the other hand, cannot readily be relaxed until the total stress exceeds the yield stress. Thus, one would expect the fatigue properties of heat-treated alloy steels to be sensitive to the presence of residual stresses. Such is indeed the case. On the other hand, one seldom finds high-temperature applications in which residual stresses persist long enough to influence fatigue properties. The relaxing effect of temperature coupled with that of cyclic plastic flow serves to dissipate residual stresses very rapidly.

In view of the tendency of residual stresses to relax, investigations of the effects of residual stresses on properties should always include provision for measuring residual stress after testing as well as before.

Conclusions

On the basis of current knowledge of dislocation behavior and plasticity, one can make the following statements in regard to the fatigue of welds:

1. It is unlikely that any deleterious effects of martensite and bainite in welds arise from their acting as barriers to dislocation motion.

2. Martensite and bainite platelets do not behave in the same manner as inclusions and voids, and do not constitute internal notches.

3. Although they may be very important in determining static load-carrying capacity, residual stresses will often relax before causing significant damage under fatigue conditions. Whether residual stresses are important in fatigue depends on the material and its service conditions.

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Looking Ahead with the Welding Research Council

BY W. SPRARAGEN, DIRECTOR

About once or twice a year, the question is raised by someone as to the significance of the work of the Welding Research Council. Sometimes the impetus for the question stems from the need to convince an executive or group of executives that continued support for some research project seems desirable. A 48-page Year Book recently published by the Council attempts to highspot briefly the varied activities of the Council. To answer the question in a single page requires a different approach. Therefore, the subject will be treated under four typical headings.

Education

Perhaps all the other good things that might be said of the Council would pale into insignificance compared to the long-term value of its educational efforts.

The most obvious examples of its educational work is the placement of as many of its projects in university laboratories as possible. These project funds help, in a small measure, to increase the salary of the professors working on the projects; in fellowships for graduate students; in supplying special apparatus; in making token payments to overhead, and, above all, in bringing both professors and graduate students in contact with the needs of industry. Eventually, of course, industry benefits from the availability of these trained graduate students who might otherwise have sought other fields of endeavor.

Education is not a static thing. It continues throughout the professional life of engineer and scientist. The Welding Research Council, through its varied committees and subcommittees, provides an opportunity for groups interested in a specific subject to get together, discuss their common problems, interchange ideas, and talk with the scientists engaged in active work on the project. The subject will also be touched upon in the three other aspects covered in this article.

One of the most interesting aspects of the educational efforts of the Council is the shortening of the period of time between discovery of scientific facts, and information and application by industry. In part, this comes about through representation of code-writing groups on research project committees of the Council, in part through the actual research, and in part through the development of plausible hypothesis, as will be explained under the next heading.

Development of Hypothesis or Theory

Through the years, the Council has developed certain rules of procedure in the conduct of its projects. One of these is the encouragement of committees of the Council to develop certain hypotheses or theoretical analyses before undertaking research programs and then designing the program to prove, disprove, modify or extend these theories and hypotheses. Of course, once a plausible theory, or hypothesis, is developed, there is nothing to prevent the engineer from utilizing his judgment in the use of the hypothesis in solving his own problems even before the research work is completed.

In any event, such theory and hypothesis reduce the experimental work to a minimum and make the actual test results much more widely useful. It serves also to give all concerned an understanding of the "reasons why" certain things happen which could not have been obtained by a mere collection of experimental test results. Sometimes such an understanding points the way to wholly new means of accomplishing the same results and of solving some problems in other closely allied fields.

Dissemination of Research Information

The writer has often said that "science knows no geographical boundaries." A good idea developed here, or abroad, may be extremely important. One of the tasks which the Council has set for itself is the dissemination of research information in closely allied fields. The principal medium continues to be the *Welding Research Supplement*. Longer and of more-limited-interest reports are published as Bulletins. A relatively new publication, "Welding Research Abroad," is designed to make foreign welding research results available to engineers and scientists in the United States. Results of long periods of research in specific fields are summarized in the form of books.

Other special efforts include the preparation of special literature reviews and interpretive reports by outstanding experts on specific controversial subjects.

Projects

It is obviously impossible in such a short space to cover all the research projects of the Council. Two of the largest will be mentioned and their objectives and accomplishments simply stated.

The Pressure Vessel Research Committee, through its many subcommittees and its annual quarter of a million dollar research program, has resulted in (1) a better understanding of how to utilize carbon and low-alloy steels to the best advantage; (2) the reduction of stress concentrations at openings, supports, attachments, head-to-shell connections, and the like; and (3) information on how to control fabrication procedures, including welding to the end that code-writing bodies may in turn lower the "factor of safety" and still increase the actual safety of the vessel. This in turn will enable industry to utilize higher combinations of temperature and pressure, and meet unusual demands in special application involving thermal shock, fatigue or corrosive conditions.

Three current investigations of the Structural Steel Committee will change and modify current practices in cantilever beams, rigid-frame structures and the linear buckling theory in the design of plate girders. Not only is actual saving of steel and money indicated, but new concepts in design are becoming available.

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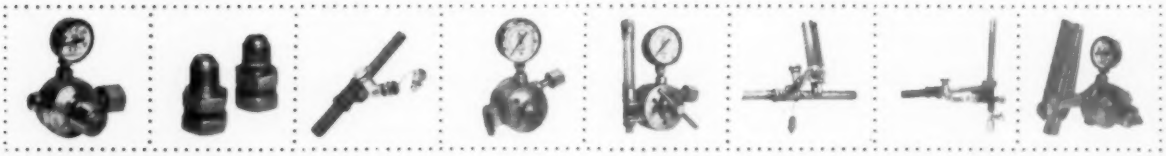

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